

Rust Never Sleeps

A Search for Family History and Boyhood Science

18 January 2021



Tom Calderwood

NOTES TO REVIEWERS

The intended reader is someone who buys titles in the "science" section of a bookstore, but who enjoys human interest as a significant part of a story. The major themes are metallurgy, chemistry, and the life of a 19th century Scottish tradesman.

"FIXME" tags indicate specific textual points in need of attention. A particular puzzle is how to consistently express pounds/shillings/pence in various tables and graphs. All tables are presently marked FIXME on the presumption that they will be reformatted in final typesetting. There are a few places where the LibreOffice editor cannot format certain characters as I want, and I have marked those with "TYPOGRAPHY." Also, LibreOffice lacks an equation editor, so all chemical and algebraic equations are marked FEQUXME.

All images and figures, along with their captions, should be regarded as placeholders. Figures (including electronic images obtained elsewhere) are noted with "FIGSME". Actual photographs are noted with "PHIXME." Current captions include the name of the file from which the graphic comes, except in the case where said graphic is borrowed from elsewhere and must be replaced. All images and figures not in the "Color Plates" section will be rendered in monochrome, even where in color in this draft.

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(PHIXME jacket photos are jandrew.jpg, jchisel.jpg, and jflask.jpg)

Table of Contents

Preface.....	5
East Kilbride.....	6
Heavy Metal.....	17
Life of a Joiner.....	37
Some Like it Hot.....	46
The Tools Go Back to Work.....	64
Keeping it in the Family.....	92
Death of a Paper Clip.....	100
"Harmless Lunatics".....	115
Rust Never Sleeps.....	125
Coming to America.....	138
Iron from the Stars.....	151
Coda.....	164
Acknowledgements.....	166
Appendix: Teaching Chemistry as History.....	167
Bibliography.....	169
References.....	169
Papers Concerning Tycho's Supernova.....	171
A Chemistry Reading List.....	172
Index.....	173
Color Plates.....	174
.....	175
.....	176



PHIXME (frontis.jpg)

Preface

In my hand I hold a tool that would not look out of place in a medieval armory. It's a foot-long chisel from 19th century Scotland and it belonged to my great-grandfather, Andrew Calderwood. The blade was made by Ward and Payne, a large toolmaker of Sheffield, England. The handle is aged, cracked beechwood held together by black tape at the hilt. It weighs over a pound and looks like it could go through sheet iron. Andrew was a *joiner*, a kind of carpenter, who learned the trade from his father. Andrew worked in the Calderwood joinery business and later tried his hand at dairy farming, but Scotland would not be his family's future. In 1908, he packed up his wife and children and headed to North America: first to Canada, then the United States, settling in Portland, Oregon. He was the archetypical immigrant, searching for a better life in the new world, a life to which I am heir.

On my desk is another tool, of sorts: a glass flask from my childhood. I grew up in the golden age of chemistry sets. A 1968 Christmas picture shows me opening a box from the Oregon Museum of Science and Industry (OMSI), a box almost half as big as I, containing my first collection of real apparatus and chemicals. Mom had enrolled me in chemistry classes at OMSI the previous summer, and I had a grand time with flames, potions, glass tubing, and litmus paper, as only an eight-year-old could. As time progressed, I got more glassware for my home use, as well as chemicals like ammonium dichromate to power volcanoes, and hydrochloric acid to dissolve metals. Chemistry was very fun, then, but as I went through the educational system, its allure was dimmed and almost lost.

The blades of Andrew's tools are made of steel, the most important material of the Industrial Revolution. It remains ubiquitous in our lives and it has a chemistry all its own. This book is a tale of two quests: for my great-grandfather and for my love of chemistry, united by the metallurgy of his tools.

East Kilbride

Officer: "What brings you to Scotland at this time?"

Me: "This is the one-hundredth anniversary of the Calderwood family leaving Scotland."

Officer: "Did they leave voluntarily?"

Such was my welcome at the immigration desk of the Glasgow airport. In June of 2008, I had come to Scotland to see the family's ancestral home for myself. Andrew Calderwood lived in the parish of East Kilbride, Lanark County, Scotland, about seven miles south of Glasgow. I had already done considerable research in preparation, and would now have the opportunity to add new details to the story.

Scotland is noted for rivalry and treachery, and East Kilbride's history is entwined with some of the best thereof. A messy royal succession followed the 1287 death of King Alexander III. His heir, granddaughter Margaret, died during her minority and members of the Balliol and Bruce families became contenders for the Scottish throne. The rival clans agreed to have Edward I of England arbitrate their claims as a supposedly neutral party. But Edward was looking to control Scotland for himself. He chose John Balliol as the rightful king and turned him into a puppet.

Edward subsequently invaded and conquered Scotland and John was imprisoned in London. Robert the Bruce then teamed up with John Cromyn

(nephew of Balliol), to become “guardians” of Scotland against the English. At that time, East Kilbride was largely in the control of the Cromyn family. Were Scotland to regain independence, John Cromyn would be the chief rival to Robert the Bruce for the crown. So in 1306, Robert stabbed him to death in a church. The East Kilbride lands were seized from the Cromyns, and Robert gave them to his daughter Marjory and her husband, Walter the Steward (Stuart), who would begin the line of Stuarts that eventually ruled Scotland and England.¹



FIGSME Scotland map (REPLACE)

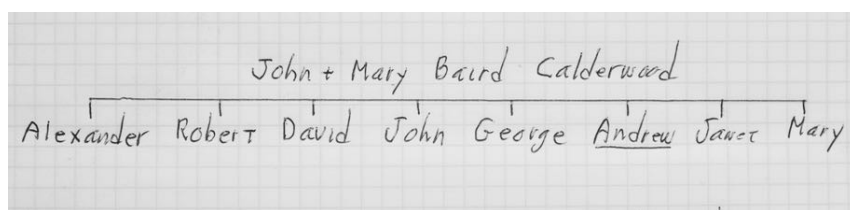
Common people in East Kilbride lived largely by farming until the late 18th century, when weaving and shoemaking became cottage industries. A railway link to Glasgow was established in 1868, making it possible for residents to work in the city and for new local commerce to take root. The town even became a kind of health resort for the soot-bound city dwellers. After World War II, East Kilbride was chosen for redevelopment under the "New Town" program. A planned urban community was erected on 10,250 acres, whose existing buildings vanished under the bulldozers. Circa 1800, the town had about 2400 inhabitants; today the population is roughly 75,000.

1 This is a highly compressed version of the events. Scottish politics were very much a contact sport.

Calderwood is a Celtic name, a calder being a wooded stream. The legend of the origin of the family is related by David Ure in his 1793 book, *The History of Rutherglen and East-Kilbride*:

That the surnames of Torrance and Calderwood originated in this parish is not improbable. Concerning the latter, the following story is handed down, by tradition, among the family of Calderwoods in the shire of Ayr. They say, "that, at a remote period, there lived in Calderwood, in Kilbride, a family of the name Calderwood, whose forefathers had, from time immemorial, possessed that place. This family, at last, consisted of three sons and a daughter. The sons having unhappily quarreled with the parish priest, and finding it not safe to remain any longer in Calderwood, fled for protection to the Earl of Cassils, who gave them three separate farms; namely, Peacockbank, and Moss-side in the parish of Stewarston; and the Fortyacre land in Kayle. These brothers had numerous families, which, in a short time, spread the name of Calderwood though the county. The sister, who was left in Kilbride, was married to a gentleman of the name of Maxwell, who got, by the marriage, the whole of her father's estate." If this story (which I heard from one of the descendants of the brother who settled in Peacockbank) is true, it is probable that Calderwood anciently belonged to a family, bearing the name of the lands they possessed.

Andrew, born in 1849, was preceded in East Kilbride by at least two generations of re-established Calderwoods. The 1841 Scottish census lists his father, John Calderwood, as a wright (a worker in wood), age 29. At the time, John lived with his wife Mary, son Robert, three wright's apprentices, and a young woman servant.² Ten years later, the household had grown to include sons David, John, George and my Andrew, and by 1861, daughters Janet and Mary. John Sr.'s occupation was then listed as "joiner employing four men and two boys."



FIGSME John and Mary Calderwood family with children surviving to adulthood

2 Eldest son Alexander was evidently living elsewhere.

In 1881, Andrew was still at home, unmarried. The census listed both Andrew and his father as "master joiner employing 10 men," with daughter Mary the only other child in residence. But by 1891, Andrew was finally wed, living as a farmer with four children of his own, ages six years to nine months, on a nearby dairy farm known as Rigghead.³ 1901 saw him still on the farm with three more children, but that would be his last appearance in the Scottish census, and the rest of the relatives in East Kilbride would peter out in a few decades. The joinery workshop is now gone and Rigghead farm lies under an office building. The only traces of the Calderwoods are headstones in the cemetery and a house once owned by Andrew's eldest brother, Alexander.



PHIXME Andrew and Margaret Rae ("Nanny") Calderwood family. L-R: Mary, George, Anne, Robert, Andrew Jr., John (standing), Margaret Rae, Margaret, Andrew.
(family.jpg)

3 Also known as "Righead."



PHIXME "Nanny"
(nannieA.jpg)



PHIXME Nanny's locket with Andrew's picture
(locketA.jpg)

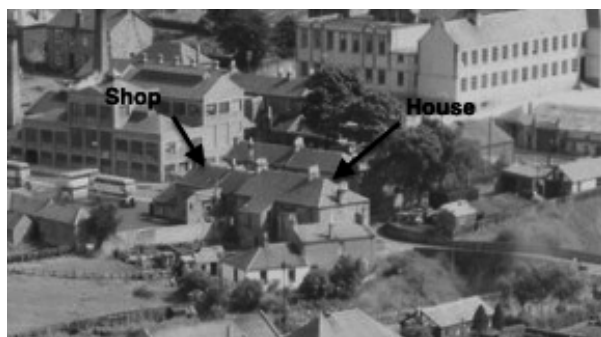
Andrew's father must have been a prominent figure in the town. His 1895 obituary reads as follows:

We regret that we have this week to chronicle the death of Mr. John Calderwood, at the ripe age of 84 years. Mr. Calderwood, who died at his residence early on Tuesday morning, carried on for a large number of years a very extensive and successful joiner and cartwright business, but retired some years ago in favor of his eldest son, Mr. A[lexander] Calderwood. He was a man greatly respected in the community, of unimpeachable integrity and urbane disposition. He held sound and advanced opinion on all public questions, and the special knowledge which he derived from the pursuit of his business was turned to good account. Throughout his business career, he was a persevering and painstaking man. He was a devoted member of the U.P. [United Presbyterian] Church, and for half a century, we believe, officiated as the Communion table elder. Much public sympathy is expressed for the sorrowing family circle, which has been narrowed by two bereavements within the space of a week, and on the members of which this second bereavement have fallen with even more than ordinary severity.

John Calderwood's United Presbyterian church, known as the West Kirk, was, true to Scottish factionalism, a splinter off of the Old Parish Church of East Kilbride. But splinter or no, the members of the Kirk were still buried in the Old Parish graveyard, and I found John occupying site number 213 with his parents, Alexander and Mary, and his own wife, Mary. In yet another turn of

local history, maintenance of the cemetery is the responsibility of the civil parish, not the church. Not far from John Calderwood is the crypt for the Stuart family. Some years ago, it fell into disrepair and became a safety hazard. The living relatives of the Stuarts had no interest in funding its reconstruction, and the Parish Council, rather than come up with the money, erected scaffolding to hold the structure together. Now the scaffolding is falling down.

To my disappointment, I learned that Calderwood castle never belonged to the Calderwood family, being, instead, the home of the Maxwells for most of its existence. It took its name from the place associated with the Calderwoods, and is supposed to have been built before the 14th century, with later extensions. The last Maxwell died in 1885 and the deteriorating building was demolished in stages starting in the late 1940s.



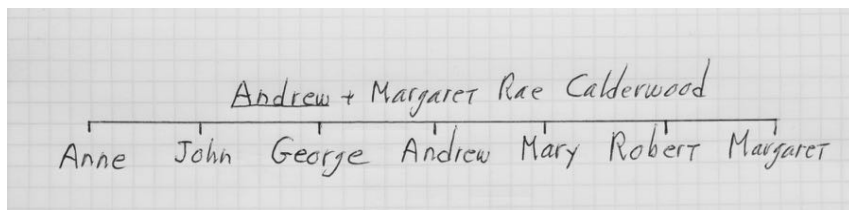
FIGSME John Calderwood house and shop from the air (house_shop1B.jpg / CPE_SCOT_236 FFO_0184 PERMISSION)



FIGSME End-on view of house and joinery shop, looking down Parkhall St. Shop is at near end, house is behind it. Anonymous undated photo courtesy Bill Niven. (house_shop2A.jpg)

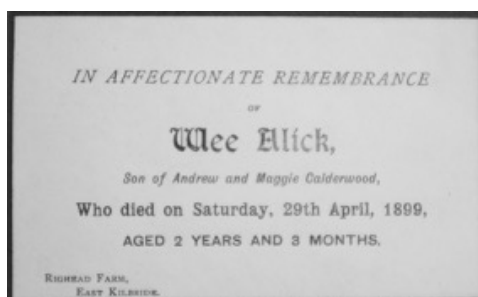
John Calderwood's house adjoined his workshop on Main Street (also known as Parkhall St). An 1860 visitor wrote: *"Took tea with John Calderwood, saw there his Brother in law George Baird, from Glasgow, and his mother from Jac[k]ton. Mr. Calderwood has a very fine finished house and well furnished."* The 1837 East Kilbride directory lists John as one of three wrights in the parish. The other trades represented were: cooper, saddler, tailor, clothier, blacksmith, boot and shoe maker, grocer and spirit dealer, vintner, baker, mason, flesher (butcher), nail maker, and flax dresser.

I acquired my copy of the directory the through the East Kilbride Central Library. On my first full day in Glasgow I took the bus to East Kilbride to visit the place. The directions I was given were to go to the shopping mall and, once there, anyone could direct me to the library. I thought it was curious that typical mall shoppers would know the way to a library, but upon my arrival I found that the mall *housed* the library. The repository is frequently used for family research, and I had made prior arrangements to meet with librarian John McLeish of the genealogy department. To my delight, he provided me with a packet of materials bearing on the Calderwoods, including the above diary entry of taking tea with John (their indexing system must be extraordinary). Copied maps of the parish showed the location of the house and workshop, and of Rigghead farm. There were also aerial photographs of the parish, taken shortly before the New Town project began, and relevant newspaper clippings.



FIGSME Andrew and Maggie Calderwood family with children surviving to adulthood

Andrew Calderwood married Margaret Rae in 1884, who bore him eight children: Anne, John, George, Andrew Jr., Mary, Robert, Alick (Alec), and Margaret. The first-born son in each Calderwood family was named for the *grandfather*, not the father, so there are alternating John/Alexander heads of households through the generations, making for confusing genealogical research. "Wee Alick" died at the age of two, and we have a notice of his memorial.

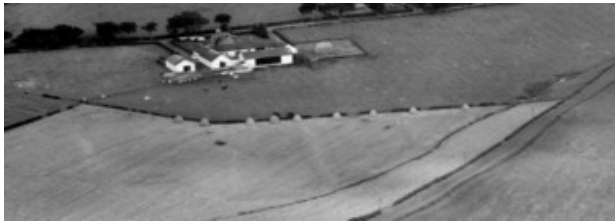


PHIXME Alick memorial notice (alick.jpg)

While in East Kilbride, I went to see Holm Cottage, the only Calderwood property to have survived urban renewal. The owner, Brian Gayne, is accustomed to history-seekers stopping by, for the place was used as a headquarters for the Home Guards during WWII. He kindly moved his car from the front drive for the benefit of my camera and let me come inside. This house was apparently the last residence in East Kilbride used by someone in my branch of the Calderwood family: Janet, Alexander's eldest daughter, who died widowed in 1940.



PHIXME Holm Cottage, 2008 (holm2A.jpg)



PHIXME Rigghead farm from the air (farm1.jpg / CPE_SCOT_UK236 FFO_226.jpg
PERMISSION)



PHIXME Rigghead close-up (farm2.jpg / CPE_SCOT_UK236 FFO226.jpg
PERMISSION)

Growing up in Portland, I knew my great-aunts Mary and Peggy (Margaret), and my grandfather Robert. I saw Uncle John only once or twice, in a Salem,

Oregon nursing home. Unfortunately, my grandfather, whom I saw fairly regularly, had no sentiment for Scotland and never talked about it—he had even lost his accent. My own father remembers hearing only one story, about a pet goat that fell into the molasses barrel on the farm. Aunt Mary was more enthusiastic about the old country, sometimes giving Scottish-themed presents at Christmas. Andrew Sr. died before my father was born, but Dad knew his grandmother well. “Nanny” was a fixture in the family, living nearby, and he recalled that she could handle the grandchildren, “Like a top sergeant,” if need be. In the 1950s, when most all of the clan was still living, they would gather at my grandfather’s house for holiday celebrations.

Anne Calderwood ventured back to Scotland in 1956 with her sister-in-law, Marian (“Min”) Calderwood, the wife of Andrew Jr. They visited East Kilbride while the New Town project was under way:

Rain again so I took a taxi to Mabel's, E[ast] K[ilbride]. Minnie came along and visited Mrs. Rue on the Market Hill. After dinner Andrew [Baird] took Mabel and me for an auto ride around the new town. We went up to Rigghead and Mabel and I called on the people living there. The place is a wreck. They expect to build a main road throughout the farm and all the buildings will be torn down in the future. Our beautiful front door entrance had shelves on both sides with milk bottles, etc. She took us through the hall and out a door into a garden which has been built between the bedroom and kitchen. All of the old house including the old kitchen was a shambles, all the windows out. The barn is filled in and the ground built up so it doesn't look like the Rigghead we knew. Blocks of apartment houses all around.

This is the last eyewitness testimony my family has to old East Kilbride and the Calderwoods' place in it. Looking back, it's tragic that my sister and cousins and I never inquired for details of that history while the principals were still alive. Even my father's younger sister, Lois, once remarked that she wished she had talked to Nanny about Scotland while she was growing up. The first time I recall having a serious curiosity about my forebears was when my grandfather moved to a retirement community. He had a large collection of tools that could not go with him, most of which were dispersed. I was off at college at the time, but I heard that there were some hand tools from Scotland and I never forgot about them. In 2004, when it came time for my own parents to downsize, I was there to help sort and pack. Unbeknownst to me, my father had become the keeper of the Scottish tools and I found them. There were chisels, gouges, planes, marking gauges, measuring tools, boring bits, and a

chest. Not a very complete collection, actually, but enough to ignite my interest in their owner, his life, and his work. I began to research the tools—their makers and uses. I joined historic tool organizations, I took some woodworking classes, and I pressed family members for tidbits of history that had survived. With the trip to East Kilbride, my hunt for Andrew began in earnest.

Heavy Metal

In eighth grade science class we had chemistry and physics units based upon fairly sophisticated experiment kits. I don't recall much about the curriculum; what sticks in my memory is the fun my lab partner and I had dissolving coins in the nitric acid, making billowing, acrid smoke that we collected in an overturned aquarium. One day the class made hydrogen gas. Hydrogen is flammable, and I drew some off in a plastic syringe for my own experiment. We were using alcohol burners, and I thought I would be able to boost my burner's flame by squirting it with a stream of hydrogen. I had purely innocent intentions, but in the proper combination with oxygen, hydrogen is not just combustible, but explosive. I evidently had just the right mixture, for the burner's flame followed the hydrogen back into the syringe, and, with a loud *pop!*, the cylinder leapt off of the plunger and flew across the room, nearly hitting another kid. After this incident, which took place with the principal standing behind me, I was invited to try my experiment *after* school, with the syringe safely pointing out a window. I did this, but failed to get a single ignition.

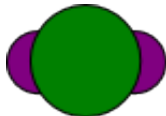
Lest it be thought I was a mere clown in class, I will recount a notable event: we were doing an experiment with an electromagnet and a balance beam. Actually, I was not doing it, the school athletic star, Burkie, was. The workbooks allowed students to proceed at their own pace, and he was weeks ahead of me. The idea of the experiment was to energize the electromagnet with a battery; it would attract an ordinary magnet fixed to one end of the beam and thereby pull the beam down. But Burkie's beam kept going up, repelled by the electromagnet, and he couldn't figure it out. Despite my lagging pace in the coursework, he asked me for help. My understanding of electricity was far from complete, but I knew it mattered which way you hooked up a battery—you might get the opposite of the effect you want. At my suggestion, he reversed the wires, the beam descended, and I was confirmed as the true scientist of the class, at least in *my* mind.

* * *

The science of metals, metallurgy, is a branch of chemistry; in particular, chemistry of the solid state as opposed to the gaseous or liquid states. While chemistry is usually associated with bubbling liquids and reactive gases, solid substances are every bit as "chemical." Steel, for instance, is a solution of one solid (carbon) dissolved in another solid (iron), with no liquid medium. Chemistry is ultimately about atoms, the chemical elements, and the myriad ways they can combine. *Atomos* is a Greek word meaning "non-cuttable," and it is only in the last hundred years or so that chemists knew that atoms had internal structure and individual pieces. For our purposes, the most important characteristic of these pieces is electric charge. There are positive bits, negative bits, and neutral bits. The positive and neutral bits live in the center, or nucleus of the atom, while the negative bits whirl about the nucleus like a cloud of comets. These negative bits, called electrons, are the lifeblood of chemistry. Almost all chemical change is due to the movement and re-arrangement of electrons.

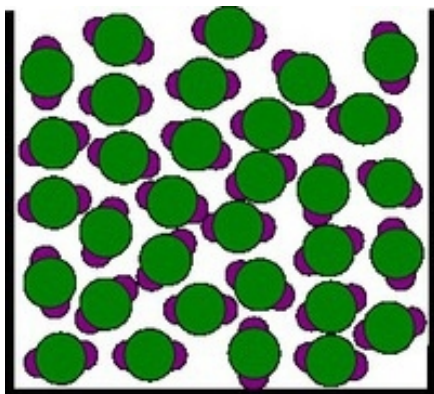
Atmospheric clouds come in layers: stratus (low), altostratus (middle), and cirrus (high). Roughly speaking, an atom's electron clouds are also organized in layers, something like an onion. When one atom interacts with another, the properties of their outer electron clouds primarily determine the result. An electron cloud deck is most stable when it causes complete overcast of everything below, and upper decks generally do not form until all lower decks are complete. However, the cirrus deck of most atoms is not naturally full, and each such atom seeks more electrons to fill it up. Two or more compatible atoms, in close proximity, can share their partial cirrus decks to create a complete overcast around themselves and become a molecule. This sharing is the most common kind of chemical bond.

Consider a water molecule: one atom of oxygen (atomic symbol: O) and two atoms of hydrogen (atomic symbol: H). Roughly speaking, the combined cloud looks like this:



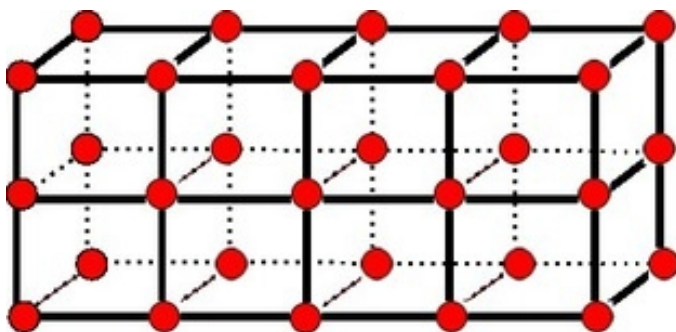
FIGSME H₂O MOLECULE GRAPHIC (water1.png)

A bucket of water is just a collection of many such molecules:



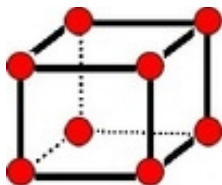
FIGSME WATER BUCKET GRAPHIC (bucket.png)

Each water molecule is self contained and does not bond with other water molecules. For this reason, you can easily move your hand through water. But your hand will not so easily go through the metal wall of the bucket. This is because the metal atoms are arranged in a *lattice*, a strong molecular structure. Here is a simple lattice:



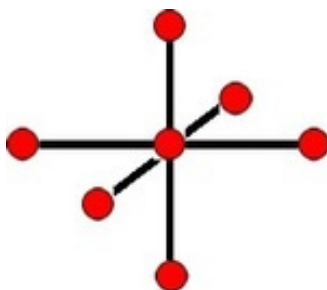
FIGSME lattice (lattice1.png)

Every lattice has a basic building block that repeats over and over in three dimensions. The building block of the above lattice is a cube.



FIGSME lattice unit cube (cube.png)

Each sphere in the lattice represents the nucleus of an atom and its lower cloud decks. The lines show the paths of sharing for the cirrus electrons. If we look at any single atom, we see that it is bonded to six adjacent atoms.

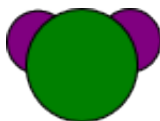


FIGSME lattice bonds (corner.png)

This structure is what gives the lattice its strength. An ideal lattice would go on forever, but a physical lattice has edges. The atoms on the edges do not get to complete their cirrus decks, but they are still strongly bound in place.

The positive bits of an atom (called protons) and the electrons are quite small, and their individual electric charges are equally small, but by their sheer numbers they can exert tremendous force. For example, consider the water molecule: I drew the three atoms in a straight line, but the reality is different.

H₂O actually looks like a Mickey Mouse head, with hydrogen ears and an oxygen face.



FIGSME water molecule (water2.png)

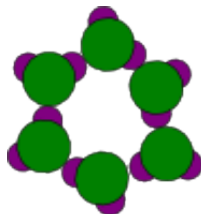
Ordinarily, an atom is electrically neutral, with equal numbers of positive and negative bits. The hydrogen atom has only a single proton and single electron, while an oxygen atom has eight of each. When hydrogen shares its electron with oxygen, the resulting tug-of-war between the single hydrogen proton and the eight oxygen protons pulls hydrogen's electron closer to the oxygen. This makes the oxygen atom slightly negative and the hydrogen atom slightly positive. Simplified, the distribution of electric charge on the water molecule looks like this:



FIGSME electric charge (water3.png)

Hence, the molecule is polarized: one side slightly positive and the other slightly negative. Like the north and south poles of magnets, opposite charges attract. When water is in a liquid state, the molecules move about freely but are loosely attracted to each other—positive parts to negative parts—by the polarization. This weak bonding produces the surface tension that supports water-striders and pulls small dollops of water into round droplets. But as the temperature approaches freezing, the random motions of the molecules almost

stop. As they slow down, they are not merely attracted to each other, they start to hard-interlock according to charge, producing a six-sided unit that repeats:



FIGSME ice lattice (ice1.png)

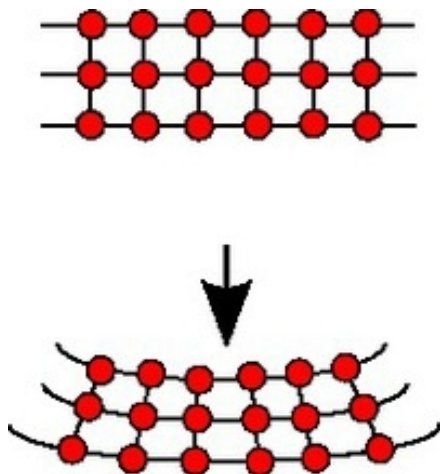
This is the beginning of a water lattice (ice). The tremendous force that holds an ice block together is nothing more than the attraction of tiny electric charges on the water molecules. The vacancy in the center of the ice crystal takes up space, causing expansion that can burst the strongest pipes.

Though individual electrons repel each other, they are drawn together in atoms by the attraction of the positive protons in the nucleus. The laws of quantum mechanics organize the electrons into cloud decks, and prevent them from falling all the way in. Quantum mechanics further governs the electron sharing that makes most of the chemical bonds in our world. This quantum force is generally not as strong as the electric force, but it does not need electrical polarization to have effect.

Metals are good conductors of electricity. The metallic cirrus clouds are brimming with electrons—so many that a metal lattice is practically a fog of electrons. These electrons are the carriers of electricity, and their motion constitutes electric current. The bonds between metal atoms in a lattice are strong, but many individual electrons are held only loosely. When a wire is hooked across a battery, the battery voltage induces force (an electric field) throughout the wire. This force makes the loose electrons hop from atom to atom across the lattice and out one end of the wire. These departing electrons are replaced by new electrons from the battery in a continuous flow.

The links between lattice atoms are not perfectly rigid: think of them as very stiff springs that can stretch or compress. Speaking simply, If we take a three-

layer lattice and bend it slightly along its length, the links along the top shrink, while those on the bottom elongate:



FIGSME stressed lattice (exaggerated) (bendA.jpg)

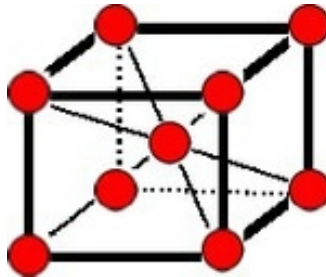
If we release the bending force, the lattice snaps back. This is how a metal spring works, but the effect can only go so far. If we continue bending, the stretched bonds on the bottom will eventually break, and the now-separated atoms will look to partner with other atoms. Also, the compressed bonds on the top will refuse to shrink further, and the atoms will begin to slip past one another, breaking the old bonds and forming new ones. With the atoms rearranged, the metal will not return to its original shape. It is *sprung*. This effect is not necessarily bad. When we make an elbow joint from straight copper pipe, we want the joint to stay bent. The beauty of copper is that it will bend ninety degrees without rupturing. It is a *malleable* material. Clay pipe is not malleable. It will shatter when bent because the atoms in a ceramic material are held together by inflexible bonds that cannot adjust or re-arrange. Malleable metals are widely used in manufacturing. They can be hammered, stamped, squeezed, twisted, and bent into wondrous shapes. All the steel bodywork of your car started out as flat metal sheets that were pressed into shape by

"tooling" in massive presses. The tools are expensive to make, but once built they can stamp out body parts by the millions.

* * *

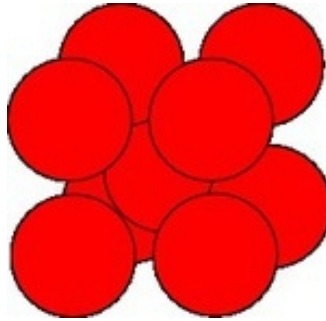
Wrought iron is the blacksmith's stock-in-trade. It is a soft metal and, when heated, can be hand-hammered into a variety of useful shapes. Iron ore is widely available, and making usable metal from the raw ore is not too difficult. However, the softness that recommends iron for fashioning simple implements is also its limitation: iron is not suitable for tools that must endure rough treatment. An iron cutting blade will dull quickly, or even bend during heavy use. Metal tools must be hard, and wrought iron lacks this property.

An iron lattice is more elaborate than the simple cubic example, above. Besides the atoms at the corners, the repeating element also has one in the center:



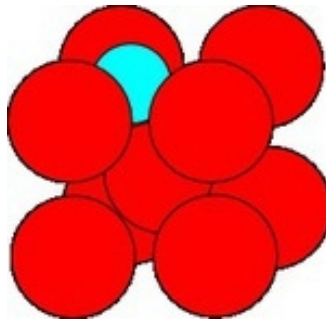
FIGSME iron lattice cube (iron.png)

This is the form of iron at common temperatures. It's known as a body-centered-cubic lattice, or BCC (the additional atom being located in the "body" of the cube). In comparison to the size of the above-illustrated cube, the actual iron atoms are much larger than I have drawn:



FIGSME iron lattice “actual” proportions (big_iron.png)

The iron atoms occupy most but not all of the lattice space, and this is the key for making steel. Steel is an alloy, or solid solution, of iron and carbon. There is room enough for a carbon atom to squeeze into an iron cube, if you push it a bit. The carbon atom does not bond with the iron, it merely occupies space inside the lattice and slightly shoves apart the iron atoms.



FIGSME carbon in lattice (iron_carbon.png)

The presence of carbon makes an iron lattice hard. In simple terms: by taking up space, the carbon atoms limit the freedom of the lattice to stretch or compress under load. The science of steelmaking hinges on the ability to control the amount of carbon in the lattice. If too little, the result is soft wrought iron; if too much, it is brittle cast iron. In between, it is steel that can

be made into tools. Soft steel has roughly one carbon atom for every eighty-six iron atoms; hard steel, about one for every twelve—a considerable difference.

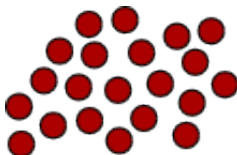
Pure metallic iron is not naturally available on Earth, except in certain meteorites. Iron is found in molecules with oxygen, usually as hematite (two iron atoms, three oxygen atoms) or magnetite (three iron, four oxygen), along with impurities. Refining iron consists in breaking the iron-oxygen bonds, and separating out the contaminants. This is done in a furnace, the earliest type of which is known as a bloomery, and the process is the essence of chemistry: the transformation of one compound into another. Let's meet the players, starting with the iron ore:



FIGSME hematite and magnetite iron ores (ore.png)

The chemical formulae for hematite and magnetite are Fe_2O_3 and Fe_3O_4 , where Fe is iron.¹ Hematite and magnetite actually exist in large, complex crystals (I drew stylized single molecules, without the links between atoms).

Next, here is charcoal, an irregular collection of carbon (C):



FIGSME carbon (carbon.png)

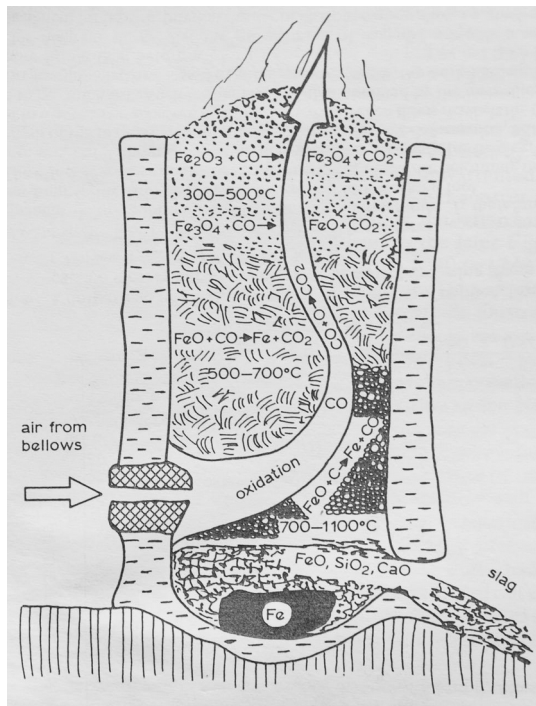
And finally, the carbon/oxygen compounds:



1 Fe is short for the Latin “ferrum.”

FIGSME carbon monoxide (CO) and carbon dioxide (CO₂) (cocoo.png)

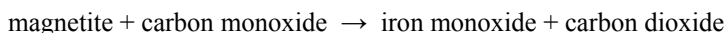
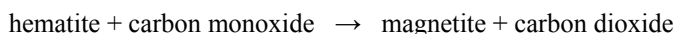
That's it: iron, oxygen, and carbon cover most everything we need to know about the reactions in the furnace.



FIGSME REPLACE medieval bloomery (after Barraclough) (bloomeryA.jpg)

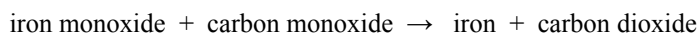
The bloomery is fired by charcoal, not too dissimilar from the briquettes in your barbecue. A layer of charcoal is laid on the hearth, and the remainder of the stack is filled with mixed iron ore and charcoal. It may contain hematite, magnetite, or both. Below the hearth is a well, where the melted products will sink, and there is an air shaft reaching into the bottom of the stack.

The refining of iron proceeds in three layers of the furnace. Throughout the stack, the fire is short of air, and the charcoal burns inefficiently, producing carbon monoxide. Carbon monoxide has a fierce appetite for oxygen. As it rises through the shaft, it removes oxygen from the iron ore. At room temperature, CO can't separate oxygen from iron, for the oxygen is held too tightly. But heat is a very effective means for breaking atomic bonds. At the top of the furnace, where the temperature is roughly 400°C,² the heat will liberate the most loosely-held oxygen atoms from the iron but leave intact the carbon-oxygen bonds of CO. Carbon monoxide then grabs those loose oxygen atoms and carries them away as carbon *dioxide* in the furnace exhaust. This extraction of oxygen turns hematite (Fe₂O₃) into magnetite (Fe₃O₄), and magnetite into iron monoxide (FeO). The two top-of-stack reactions are summarized as:



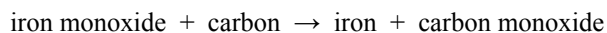
FEQUXME (2)

As the stack burns down and the iron monoxide sinks, it enters a hotter zone of about 600°C. Here, the increased heat can pry the last oxygens free from the iron, and CO again sweeps them away.



FEQUXME

Any iron monoxide that survives all the way to the still-hotter hearth can be converted directly into iron and carbon monoxide, the last oxygen atom being stripped away by "free" carbon (from the charcoal) in the 900°C heat:



FEQUXME

As the iron and impurities fall to the hearth, they become a kind of mush that collects in the well, below. The impurities, like calcium, manganese and

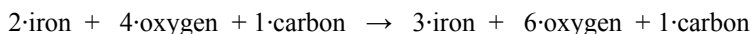
2 Temperatures in this book are given in the Celsius scale. For 400° and above, the equivalent temperature in Fahrenheit is about 10% less than double the Celsius (a little mental calculation is good exercise for you).

silicon, are not atomically bound to the iron, and because the iron is heavier it separates out and sinks to the very bottom. The metallurgist will wait for the fire to go out and the furnace to cool, then break into the well. The blob of iron, known as the bloom, is mixed with the impurities, or slag. It is removed and hammered (wrought) to break off the slag, hence the term "wrought iron." In a nutshell: carbon, carbon monoxide, and heat extracted the iron from iron oxides, and gravity separated the iron from the waste. Chemistry.

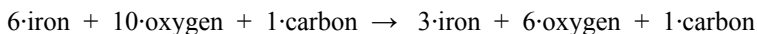
But pity the chemists. No one has ever witnessed a CO molecule acquire a loose oxygen atom—they are both too small to see, even with fancy instruments. *Precisely* what goes on in any such reaction must remain surmise. In fact, a purely literal equation for the hematite "reduction" is not correct:



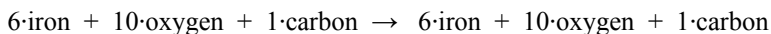
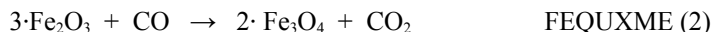
On the left side of the equation, there are two iron atoms, four oxygen atoms, and one carbon atom. On the right side, three irons, six oxygens, and one carbon. It doesn't add up. Such an equation needs to get *balanced*, a procedure that baffled me in high school. But this reaction is easy to balance, starting from the basic equation:



There is no way to turn two iron atoms on the left into three iron atoms on the right. However, what if we started with three iron oxide molecules instead of one?



Now there's too much iron on the left, but with six iron atoms at our disposal, we can form two molecules of Fe_3O_4 (and one of CO_2) on the right:



And we are balanced. From a math standpoint, what we have done is to find the lowest common multiple of the number of atoms on the right and left hand

sides that make the equation work. But more important for our story, this reveals a new aspect of the reaction: the carbon monoxide molecules do not bind individual oxygen atoms in isolation. The left hand side of the equation is a soup of iron oxides, oxygen, carbon monoxide, and cirrus electrons. As we stir the pot, the new molecules arise out of the whole mixture, not from individual participants. Indeed, there are probably some loose iron and carbon atoms—briefly separated from their oxygens by the heat—that quickly recombine into iron oxides and carbon monoxide. The existence of this kind of chemical bouillabaisse was never explained to me in class, but without it, most chemical reactions do not make sense.

I tried making my own bloomery out of refractory bricks, using a hair dryer to provide the air blast. Six four-sided hollow segments were stacked like a space shuttle booster, rising about five feet high. I charged it with crushed barbecue charcoal and some magnetite.



PHIXME Driveway bloomery (mybloom.jpg)

I live in a "cottage" community, where the residences are quite close together (the house in the background of the photograph is not mine). Hence, actual firing of the furnace was a step to be taken when the neighbors were not at

home. Alas, my bloomery only got up to about 800°C and then only briefly; all I got out of it was ash and slag.

Over the centuries, various furnace technologies were employed for refining iron in central Asia, the Middle East, China, Africa, continental Europe, and England. By crudely controlling the fraction of carbon that remained in the iron, early metallurgists could make wrought iron, cast iron, and steel, the latter being the most sensitive to carbon content and the most difficult to make consistently. But steel could be made outside the furnace, and it was probably the blacksmiths who discovered the technique.

A blacksmith heats his wrought iron in a fire before hammering it, and the fire is typically charcoal. Wrought iron is deficient in carbon, but charcoal is almost entirely carbon. Deep in the fire, there is a shortage of oxygen available to bind with the carbon, so the environment is rich in loose carbon atoms. The iron can absorb this carbon in a process called *carburization* and so become steel. The carbon might penetrate only deep enough to harden the outer surface of the metal, but even this effect is useful. An observant blacksmith would see that some of his iron tools developed superior edges, and with skill the area of carburization could be controlled. For instance, when carburizing the blade of a cutting tool, the tool's shaft could be covered in clay before going into the fire. Sealed from the carbon, the shaft remains relatively flexible as wrought iron, while the edge would be converted to steel.³

The most successful method of carburization was the *cementation* process. It became prevalent in England in the 17th century, not ceasing completely until 1951.⁴ Cementation used a new kind of furnace that heated a sealed stone chest in the fire. Wrought iron bars and charcoal dust would be loaded into the chest and heated for several days or longer. Heat expelled carbon from the charcoal to be absorbed by the iron.

Cementation is an example of *diffusion*, another important chemical process. Diffusion, in general, is the spreading of some material from a region of higher concentration to one of lower concentration, and is based upon the *random*

3 It is also possible to make steel from cast iron by burning off the excess carbon. The process is called *decarburization*.

4 A restored 18th century cementation plant, Derwentcote, survives in the town of Rowlands Gill.

walk. A human random walker starts at a lamppost (random walks always start at lampposts, perhaps because the walker is drunk and needs something to hang onto). He takes a step North, South, East, or West, and stops. Without preference, he now takes another step, North, South, East, or West, perhaps going farther from the lamppost, perhaps returning to it. He repeats this process indefinitely, and his path is the random walk.

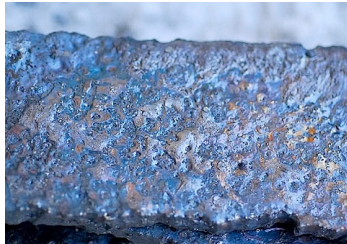


FIGSME random walk (REPLACE)

Left to himself, the walker will eventually go everywhere. If several walkers start from the same point, they will spread themselves throughout the neighborhood. You can watch the process in slow motion with a jar of water and some soy sauce. Put a dollop of sauce in the water, and it will largely sink to the bottom. But let the jar sit a day or two. With no stirring on your part, an even brown hue will spread throughout. The effect is caused by the continual jostling of sauce molecules by water molecules. Left, right, forward, back, up, down; each impact sends a molecule in a random direction. There is only one chance in six that a new step will retrace the last step, so the net effect is for the condiment to spread out. The hotter the water, the faster the diffusion will take place, for hot molecules of water jostle at greater speed and each impact gives the sauce molecules a bigger kick.

Getting carbon to diffuse into iron requires a *very* hot environment. The cementation furnace operates at about 1100°C. The heat makes iron atoms vibrate in the lattice. Gaps big enough for carbon open and close rapidly, and lucky atoms can sneak in. Sometimes the carbon is squeezed out of its pocket, but in the process, it may head deeper into the iron bar. Over the course of days of heating, carbon has the opportunity to travel throughout each bar in the chest

and induce the transformation to steel. The product was known as *blister* steel for the discolorations and irregularities produced on the surface of the metal.



FIGSME Blister steel (REPLACE)

As successful as the cementation process was, the steel produced was not the best. There were inevitable variations in the carburization, and the steel could only be as uniform as the iron bars from which it was made. The problem was that the metal was not actually being melted, either in the cementation furnace or the bloomery. A thorough mixing of the contents was not possible, nor could contaminants be completely segregated. Metallurgists needed hotter furnaces and new containers able to hold the molten metal without disintegrating. The necessary vessels were developed by English clockmaker Benjamin Huntsman, who adapted ceramic crucibles from glassmaking technology. He also built an improved furnace for heating these vessels, and started producing *crucible* steel about 1740. Crucible steel was made by melting blister steel and keeping it liquid for a few hours. The crucibles would then be lifted out of the furnace with metal tongs, and their contents poured into molds, making ingots. The manufacture of this “cast” steel would continue for two hundred years in England. It was known as the English Method, and was practiced most extensively in the city of Sheffield, South Yorkshire. The blades in Andrew’s tools were made from this metal, and the larger blades are stamped, “Warranted Cast Steel.”

Crucible steel was of high quality, and found a ready market. But the long-term viability of steelmaking faced a serious obstacle: England was running out of trees. Charcoal is a forest product, made by subjecting wood to high heat. A typical method was to build a large conical pile of timber with a chimney up the center. The pile would be covered with earth, and hot coals dropped down the chimney. A smoldering fire resulted. The heat would drive off water and

other chemicals from the wood, leaving behind a black concentrate, consisting primarily of carbon. This burned hotter and more consistently than wood, hence its use in the furnaces. Unfortunately, the making of iron required vast quantities of charcoal. As the forests disappeared, the rising cost of fuel almost put a stop to English iron production. The ironmakers needed a replacement for charcoal, and they got it from chemistry.

It is commonly conceived that a chemist's job is to synthesize new chemical compounds, but it's equally important for her to separate existing substances into their components. This can be done in a variety of ways, by exploiting the different responses of each component to the same stimulus. For instance, consider a mixture of sulfur powder and iron filings: how might we remove the iron? Iron is a metal, and sulfur is a non-metal. In fact, iron is a magnetic metal, subject to the attraction of magnets, while sulfur is non-magnetic. If we drag a magnet through the mixture, the iron will be gathered up and the sulfur will remain behind. Of course, it is messy to scrape iron filings off a magnet (especially a powerful one) but we could use an electromagnet that can be switched on and off at will.

If the sulfur is mixed with a non-magnetic metal, such as aluminum, other options exist. Many metals, including aluminum, react with acids. If we add hydrochloric acid to a mixture of aluminum and sulfur, the aluminum dissolves, while sulfur is unaffected. The sulfur crystals can be extracted from the now-liquid mixture by pouring the solution through a filter, and then drying the filter paper and its contents. Of course, we have now lost the aluminum, but it is common for the chemist to regard one component of a mixture as the product and the rest as waste.

The first of these two separations was performed based upon the magnetic properties of the components; the second, based upon the chemical properties. A third process, distillation, works upon what we may call physical properties: the sensitivities of the components to heat.

Every element, and many compounds, can exist as a solid, a liquid, or a gas (or vapor), based upon temperature. The temperature at which an element turns from liquid to solid is the freezing point; the temperature at which it turns from liquid to gas is the boiling point. Distillation takes advantage of the fact that two mixed elements or compounds may have markedly different boiling points.

By raising the temperature of the mixture to a level *between* those boiling points, one element will boil off and the other will remain.

Consider the distillation of seawater, a mixture of water (H_2O) and salt (sodium chloride, NaCl). Water boils at 100°C , whereas salt boils at 1413°C . If we heat a test tube of salt water above the former temperature and below the latter, the two compounds will separate. The salt liquifies at 801°C , so if we stay below this temperature (easy with an alcohol burner), the salt left behind will be in solid form. In this process, what is the product and what is the waste depends upon your goal. If you are running a saltworks, the water is waste material and you let it disperse into the sky. If you are selling pure water, the vapor will be the product, and it must be condensed back into liquid so it does not escape.

The manufacture of charcoal is a kind of distillation, known as *destructive* distillation since a chemical change occurs in the process. A similar process was used to produce coke, the new fuel for making iron. Coal contains the carbon the metallurgist needs, but also various compounds that are harmful to the metal. The distillation of coal, called "coking," drives out the contaminants. The coal is heated in a chamber that is largely free of air (so that the carbon does not burn), and the gasified impurities are drawn off. Again, what you regard as waste and what as product depends upon your point of view. The vapors are known as coal gas, a flammable mixture that can be burned like natural gas. Before natural gas was distributed from wells, towns had gasworks plants, where coal was distilled into coal gas that was piped out to the community. East Kilbride had such a plant. Coke eventually replaced most all charcoal in the production of English iron and steel.

I think it's remarkable that the cementation metallurgist first used heat to *concentrate* carbon from coal, and then used heat to *diffuse* carbon into iron. The same laboratory tool, put to opposite purposes, was needed to make the preferred cutting edge of the Victorian woodworker.



PHIXME Stamping on one of Andrew's plane blades: "Thos [Thomas] Ibbotson & Co
Warranted Cast Steel" (warranted.jpg)

Life of a Joiner

The term carpenter, I am told, is applicable to anyone who cuts, fashions, and joins timber for building. Those who do the work of houses are house carpenters, while those who build ships are ship carpenters. Correctly speaking, however, the framer of a building is the carpenter and the finisher the joiner: Nor, as I learn from the most intelligent workmen, can there be an interchange of labor of these two branches without an inferior degree of skill in the execution of the work being the consequence. "In my opinion," said one experienced carpenter to me, "to have the trade right well done carpenters should never be put to joiners' work, nor joiners to carpenters'. When a man's been long at carpentering, if he's put to joinering he's often too rough and rapid; and a joiner, in the same way, is too fine and finicking-like for carpenter's work."

Henry Mayhew, 1850

In Andrew's time there was no such thing as drywall, and doors and windows could not be had at Home Depot. Outfitting the bare frame of a Victorian building was a job for a local skilled laborer: a joiner. Joiners would make the window frames and sashes, doors, stairs, counters, cupboards, shutters, partitions, and skylight frames, all by hand. A typical product of the shop would have been "panel" doors that are, in a way, similar to multi-pane window sashes, except that the openings are filled with wood instead of glass.

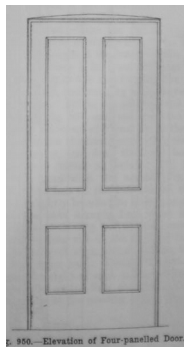


Fig. 944.—Elevation of Four-paneled Door.

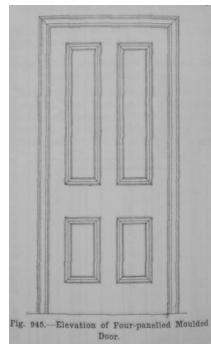


Fig. 945.—Elevation of Four-paneled Moulded Door.

FIGSME Panel doors (REPLACE, [from CARPENTRY & JOINERY])

An 1886 London builder's guide, *Skyring's*, showed the following prices for panel doors (shillings and pence¹):

46		SKYRING'S LIST OF PRICES.							
Two and a Half Inch Doors, Per Foot Super.		Masters' Prices.				Labour only.			
		All Ma- terials.		Labour & Nails.		From the Bench.		Fitted & Hung.	
		s.	d.	s.	d.	s.	d.	s.	d.
Two or three panel square	..	1	3	0	6½	0	4½	0	5½
Ditto, moulded and square	..	1	4	0	7	0	5	0	6½
Ditto, bead butt and sq.	..	1	5	0	7½	0	5½	0	6½
Ditto, bead flush and sq.	..	1	6	0	8	0	6	0	6½
Moulded both sides	..	1	6	0	8	0	5½	0	6
Bead flush and bead butt	..	1	6	0	8	0	6	0	7
Bead flush both sides	..	1	9	0	9	0	7	0	7½

PHIXME London prices from 1886. These are prices the shop master would charge the customer. One "foot super" is one square foot. (skyring.jpg)

The 19th century was a time of considerable labor turmoil. Henry Mayhew, whose quote opens this chapter, is best known for his multi-volume book *London Labour and the London Poor*, a groundbreaking social survey assembled from his newspaper writings. In an 1850 column, he contrasts the lot of men who work in "honorable" (union) shops, with those who do not:

The journeymen in connection with the "honorable" trade amount, as I have before stated, to 1,770, so that by far the greater number, or no less than 18,230 of the working carpenters and joiners in the metropolis belong to what is called the "dishonorable" class—that is to say, nearly 2,000 of the London journeymen are "society (union) men," and object to work for less than the recognized wages of the trade, while upwards of 18,000 are unconnected with the trade societies, and the majority of them labor for little more than half the regular pay.

Here, Mayhew talks to a joiner working for a "strapping² shop" of the dishonorable trade:

"I suppose since I knew the trade that a man does four times the work he did formerly. I know a man that's done four pairs of (window) sashes in a day, and one is considered to be a good day's labor. What's worse than

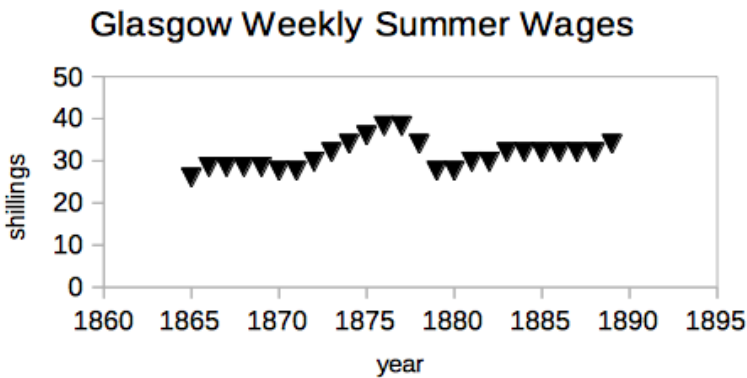
1 19th century British currency: 1 pound = 20 shillings, 1 shilling = 12 pence.

2 Whipping—administered by a leather strap.

all, the men are every one striving one against the other. Each is trying to get through the work quicker than his neighbor. Four or five men are set the same job so they may be all pitted against one another....If I was working for a fair master, I should do nearly one-third less work than I am now forced to get through, and sometimes a half less; and even to manage that much, I shouldn't be idle a second of my time."

The men working in such a shop might not be fully-qualified joiners, or they might be refugees from depressed areas. Though Mayhew describes the situation in London, similar conditions must have existed in Glasgow. Andrew, his brother, and his father were master joiners, overseeing other men. Given John Calderwood's high social reputation, I think we can assume that he ran an honorable shop.

A historical survey³ of wages in the U.K. shows the following progression of weekly pay for carpenters⁴ in Glasgow during Andrew's (approximate) joinering years:



FIGSME Glasgow carpenters' wages 1865-1889

These wages would be for summer, when more hours were worked. The drop-off circa 1879 corresponds to the calamitous failure of the City of Glasgow

³ *Wages in the United Kingdom in the Nineteenth Century*, Bowley, 1900.

⁴ Joiners and carpenters typically belonged to the same union and received the same pay.

Bank. A study of 1893 wages⁵ showed Glasgow carpenters and joiners working fifty-one hours in summer and forty-five hours in winter, for weekly wages of 36s 1½p and 31s 10½p respectively. There were no figures for East Kilbride, but joiners in nearby Hamilton were paid the same as those in Glasgow.⁶ It seems safe to assume that East Kilbride joiners received the same pay as indicated for Glasgow in the above table.

Labor rates and hours per week in the U.K. fluctuated over the years in response to demand for work and negotiations between tradesmen and employers. Over the course of the 19th century, workers were able to raise rates and reduce hours considerably. A report⁷ on British family budgets offers a context for these wages. It includes a Scots family of six, headed by an “artisan” (skilled laborer). Performing some triangulation, the following are roughly what a similar family could expect to pay in 1892 for a week's expenses:

food	rent	heat, light	taxes	clothing	benefits	life ins.	church	other
23s	3s 8p	1s 9p	1s 3p	2s 6p	1s 9p	1s 2p	1s 7p	5p
62%	10%	5%	3%	7%	5%	3%	4%	1%

FIXME Example 1892 weekly family budget. Total = 37s 1p.

The man's average weekly income for the year was 43s, boosted by payouts from membership in a purchasing cooperative. The family is probably in a commercially active area enjoying the benefits of a strong economy. Living might be cheaper in East Kilbride, but one can see the difficulty of supporting such a family on the standard winter pay of a joiner (~32s). That being said, the family would have some security. The various benefits covered unemployment, sickness, disability, death, and retirement (the personal life insurance policy was worth £100).

5 *Report on Wages and Hours of Labor Part III Standard Time Rates*, Board of Trade, 1894.

6 All these wages are for unionized workers.

7 Economic Club, *Family Budgets: Being the Income and Expenses of Twenty-eight British Households, 1891-1894*, published 1896.

The food our artisan's family bought for 23s a week included the following example dinners:

Sunday	Apple tart and tea
Monday	Soup, meat, and potatoes
Tuesday	Stewed meat and vegetables with potatoes
Wednesday	Soup made with bone, remainder of apple tart from Sunday
Thursday	Collops [meat], vegetables, and potatoes
Friday	Soup and semolina [wheat] pudding
Saturday	Stewing meat and potatoes

FIXME Weekly dinners, 1892

Bread was always served. The children, however, got none of the meat, only "sauce and potatoes" with the bread.⁸ The father of the family, in his rather extensive comments included with the survey results, lamented that many artisans were profligate with their wages and lived in hardship, or that they neglected to protect their families against an early death of the breadwinner—a common occurrence. He states that artisans "along the riverside" earn forty to sixty shillings per week.⁹

Andrew was fortunate to learn joinery from his father. A conventional apprentice spent years in service to a master, being paid little or nothing for much of that time. A look at the training process is given to us in *The Joiner and Cabinet Maker*, a book published from at least 1839 to 1883.¹⁰ *The Joiner* was one in a series of career guides for young people—a sort of *What Color is Your Parachute?* for the Victorian era. There were volumes for trades such as

8 In a particular three-week reporting period, the family divided the food budget, approximately, as follows: milk 14%, butter 14%, bread 12%, meat 12%, flour and biscuits 9%, eggs 8%, other cereals 7%, sugar 7%, fish and poultry 4%, potatoes 4%, jam and syrup 4%, vegetables 2%, fresh and dried fruit 2%.

9 Presumably summer wages. I cannot reconcile this high level of pay with the 1893 wage study, unless his fellow artisans were working overtime. The man does not identify his trade, but joiners would be among the best-paid laborers, and Glasgow men (working along the River Clyde) among the best-paid Scottish joiners. There are other details in his personal economy that I cannot account for.

10 Lovingly reprinted, with additions, by Schwarz and Moskowitz, Lost Art Press, 2009.

cooper, dressmaker, printer, shepherd, confectioner, etc. The book tells the story of a fictional Thomas Walter, following his progression from beginning woodworker to journeyman joiner.

Supposing, then, a boy of thirteen or fourteen years old, who has been accustomed to amuse himself with the hammer, who has often watched the joiner at his work, and does not know anything he should like better than to be a joiner himself, we will try to shew [sic] him what he will have to do as a joiner's apprentice.

The apprenticeship is related not just as a tale of acquiring skills, but as a morality play. The virtuous behavior of Thomas is frequently contrasted against that of his slovenly co-apprentice Sam, who never cleans his workbench or puts the tools away, who tramps dirt into customers' houses and, generally, does low-quality work. The master of the shop is portrayed as a fair man who warms to Thomas as the lad gradually proves himself. Thomas also enjoys good relations with the journeymen the master employs. A real apprentice might not be so lucky. The men, who were supposed to train the boys as part of their own jobs, might extort small payments before teaching them each trick of the trade.

The apprentice starts out as a kind of janitor, sweeping up shavings and collecting the scrap pieces of wood that accumulate in the shop. These will be used to stoke the shop's stoves or sold as fuel for the fires of others. Thomas must be careful not to collect small tools, nails, or partly finished wood pieces as he cleans the benches. His first task of serious responsibility will be managing the glue pot. Victorian woodworkers used an animal-based glue that was bought in solid form and dissolved in heated water. The novice joiner would fetch the pot for the journeymen as they needed it and ensure that it got neither too hot nor too cold on the stove. The novice will also find himself turning the grindstone, lugging lumber about the shop and yard, and running every conceivable unskilled errand.

His ticket out of this tedium is the waste wood: some of the pieces will be big enough for him to practice basic skills. As he does the menial work around the benches he observes his seniors and, with the discarded wood and borrowed tools, begins to imitate them. He must first learn to saw a straight line, both along and across the grain, in both soft and hard woods. With planes, he must learn how to flatten the faces of a rough board, and make the four sides

perfectly square to one another. Eventually, he will begin making joints between boards. These small projects become a kind of portfolio that the master can peruse to judge the boy's readiness to handle real shop work. As the journeymen become comfortable with the novice, they will start asking the newcomer for assistance when extra hands are needed. This gets the apprentice closer to the work and offers more opportunities to observe. The extent to which an apprentice can expect direct instruction is not clear. The journeymen are busy turning out the goods sold by the shop and they may be paid by the piece, not the hour. Either way, their time would be of the essence. The learning process likely took place via commentary and question-and-answer as the apprentice watched the journeymen work. If the master or journeymen perceive that the apprentice is becoming useful, perhaps the boy receives more attention. Thomas starts getting his breaks when he is able to take on work that would otherwise go undone.¹¹

In a major city, a joinery shop could practice joinery exclusively. But in a village like East Kilbride there would not have been enough construction activity to keep a firm busy making doors, window frames, and the like. In census records, John Calderwood is variously listed as a wright, a carpenter, and a joiner (the obituary adds “cartwright”). All sorts of woodworking would have been done by his business. Our fictional apprentice is also in a less-developed area. His early tasks for paying customers include mending wooden fences and outbuildings, repairing wooden appliances, and tackling simple construction jobs. As the story progresses, he moves on to furniture projects: a toy box and a chest of drawers, both of which require true joinery skills, though they would not be considered typical joiner's work.

This mixed business of rough and fine woodworking is also related in *The Village Carpenter* by Englishman Walter Rose. The book, published by the master carpenter in 1937, describes the activity in his grandfather's semi-rural shop in the years leading up to 1893. He uses the terms carpenter and joiner

11 In *The Wealth of Nations* (1776), Adam Smith rails against the apprentice system as nothing more than a means for the various trade unions to restrict the number of laborers practicing in the marketplace. He goes so far as to say that most trades could be learned very quickly—in a few weeks, at most—even if attaining full proficiency would take longer. Smith obviously never tried finish woodworking. He does say that the apprenticeship system in Scotland was the least “oppressive” in Europe (see book 1, chapter 10).

almost interchangeably and the business clearly engaged in both kinds of work.¹² As a family member, Mr. Rose enjoyed a comparatively pleasant introduction to the trade. He talks of snatching nice pieces of waste wood for his childhood set of building blocks and making toy tops to sell to other children. Before starting the formal apprenticeship, he could borrow tools to start his training, and later on he didn't have to cope with tyrannical journeymen as teachers. Andrew presumably enjoyed similar benefits.

Andrew could have participated in less savory industrial affairs, however. Another artifact that has come down to me is a *staff*—what we would call a nightstick or billy-club. The shaft is painted black, the tip bearing the lettering "VR" (Victoria Regina) and an image of a crown. These markings were symbols of authority, like a modern policeman's badge. Such staffs were issued to Special Constables. These men were law enforcement volunteers who were called out on occasion, one reason being to suppress unrest. Coal mining was a big industry in Lanarkshire, and relations between labor and capital were less than cordial. But there was strife even within the miners' ranks on account of immigration from Ireland. Scots workers resented the Irish for expanding the pool of miners and there were acts of mob violence against them. To make matters worse, some of the immigrants were descendants of Protestant Britons who had settled in Ireland. Fights between these "Orangemen" and the ethnic Irish could escalate into riots. As a constable, Andrew may have cracked some heads in the service of Law and Order.¹³



12 When I showed some of Andrew's tools to a woodworking expert, he commented that one particular chisel (a "slick") was better suited to barn-building than joinery.

13 The police records of 19th century East Kilbride are incomplete, so I was unable to learn when Andrew functioned as a constable.

PHIXME Special Constable's staff (staff1.jpg, staff2.jpg)

Some Like it Hot

I attended Benson Polytechnic High School in Portland, Oregon, whose student body was divided roughly equally between those kids who were college-bound and those who would enter the trades. All freshmen had to submit to a rotation of fairly demanding shop classes, featuring equipment that could easily dismember, disfigure, or electrocute an unwary fourteen-year-old.

In the spring of 1975 I found myself in the machine shop. One of my tasks there was to make a ball-peen hammer. From a cylindrical rod I cut off a piece of steel stock about 1½ inches in diameter and 4 inches long. I had then to mount it in a lathe where I machined the raw metal down into three distinct sections: the front head, the back ball, and the center eye, each being a different diameter. That being done, I cut flat, parallel "cheeks" into the eye section with a Navy surplus *shaper* machine, easily the most frightening device in the shop. Finally, I used a milling machine to bore out a slot for the handle. My final step, whose purpose was never explained, was to heat the finished head red hot with an impressive gas torch and then drop it into a bucket of water. I successfully made the hammer, and all my fingers lived to tell the tale.



PHIXME The Benson hammer (hammer.jpg)

A hammer head sees tremendous abuse in service. The face must absorb powerful blows against all kinds of materials without deforming in any significant way. But my hammer was made from steel soft enough to be cut

with a metalworking saw and then machined to final dimensions with the lathe and shaper. How could it ever survive in actual use? The key was the fire ritual. I didn't know it, but I was *heat-treating* the head, changing it from a malleable hunk of metal into a durable tool. To explain this, we must delve deeper into the properties of steel.

* * *

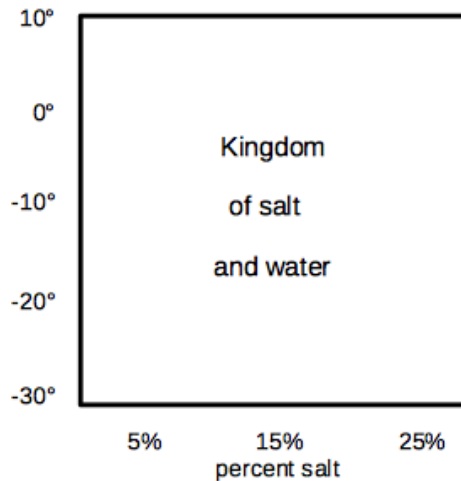
Hard. Tough. Strong. In metallurgy, these words have specific meanings. A hard metal resists impacts: it doesn't *deform* easily. A tough metal can *absorb* impacts: it doesn't shatter. A strong metal can carry heavy loads: it doesn't *yield*. These virtues don't necessarily go together in one hunk of steel, and the metallurgist must choose the right combination for different applications. I want my hammer head to be hard so it won't become pockmarked in use, but it also needs some toughness so it doesn't break if I accidentally swing it down sharply on concrete. On the other hand, I may not care if the face of my sledgehammer gets dented a bit, but the tool must survive brutal blows all day long. In contrast, I don't worry about the hardness or toughness of the steel beams that frame my office building. They needn't withstand the violence visited upon hammer heads, they must only be strong enough to carry the structural load.

The blades in Andrew's planes and chisels were of *tool* steel, a metal intended for demanding applications. These blades must be hard enough to take a keen edge during sharpening and to hold that edge in use. "Mild" steels have less than ½% carbon, but tool steels are roughly ½% to 1¼% carbon.¹ It is the higher carbon content that enables the desirable properties of tool steel, but heat treatment is needed to bring those properties to the fore. Andrew's cutting blades were so treated, so let's explore the process.

In its transition from a liquid in the furnace to a solid in the toolbox, a "heat" of steel exhibits various personalities. Technical people call these personalities *phases*, and it will be helpful to introduce a visual aid called a *phase diagram*. Phase diagrams are maps. They help us locate ourselves when we are traveling—not in space or time, but in temperature or pressure or some other physical parameter that brings on change in a material.

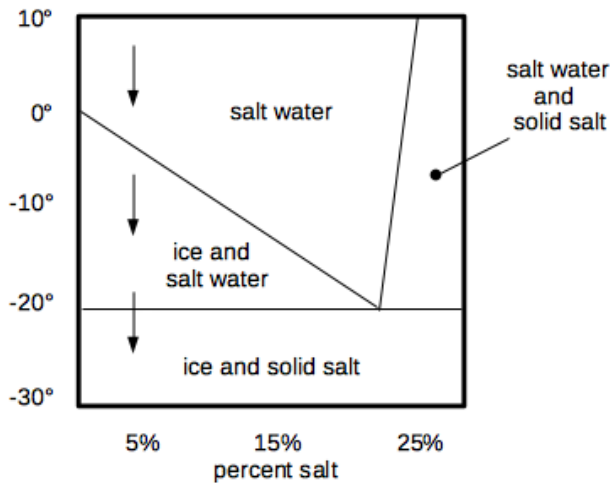
1 Percent by weight.

Below is the outline for a phase diagram of rock salt in water (covering different temperatures and salt concentrations). It is structured something like a graph: the vertical and horizontal directions are calibrated, but the axes are not years or dollars or tons. Rather, left-to-right is the percentage of salt in the mix (by weight), and top-to-bottom is the temperature.



FIGSME Temperature and concentration range for saltwater phases (salt_kingdom.png)

Within this travel space, a solution of water and salt can be all liquid, part liquid and part solid, or all solid. Let's put in the boundaries that define these phases:



FIGSME Simplified rock salt phase diagram. Arrows show cooling path for 5% salt. (salt_water.png)

The map has regions of pure salt water, salt water & ice, ice & solid salt, and salt water & solid salt. A bucket of water and salt can be made to visit all of these destinations by changing the temperature, the salt concentration, or both.

Now let's take a journey. The diagram has a dashed line for a trip from +10°C to -25°C in a 5% salt solution. Our bucket starts out with the salt all dissolved in the water. As the temperature falls to about -5°C, ice begins to form and we have slush. When the temperature hits -21°C, the salt solidifies and all the water becomes ice.

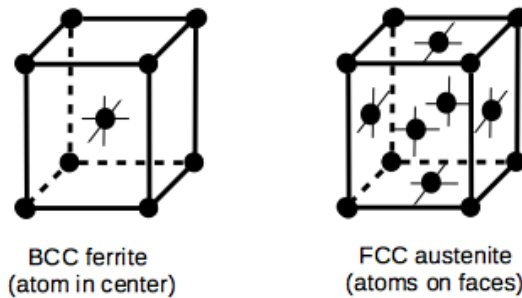
If we take a downward path at 23% salt, the mixture will stay wholly liquid all the way to -21°C, at which point it turns into two solids. If we travel down at 28% salt, at least *some* salt is always in solid form no matter what the temperature. Our rock salt is sodium chloride (NaCl). Similar diagrams, with different boundaries, exist for magnesium chloride, potassium chloride, and calcium chloride, one or more of these being the likely ingredients in your tub of sidewalk ice melter.

Steel has a number of phases, and I'll give nicknames to some of the more important ones: Austen, Ferry, Sem, Pearl, and Marten. As the molten metal cools, Austen is the first personality to appear. He emerges when the iron atoms become sluggish and begin to assume the form of a cubic crystal lattice. Along the way, carbon atoms become trapped in the cubes. This starting of the lattice is called *nucleation*, and something similar occurs in your freezer when water in an ice cube tray starts to solidify. The transition does not happen all at once throughout an ice-cube-to-be, nor does a single nucleation grow to encompass the whole. Crystals start at many nucleation points and spread without coordination. Relative to each other, the growing crystals are tilted this way and that, so when two of them collide their lattices don't line up. Atomic links are still formed across these boundaries, but the interiors of both ice and steel are composed of many lattice nodules, or *grains*, that have come together at odd angles and have mutually arrested each other's development. As the heat solidifies completely, we get not one Austen, but many Austens, fitted together irregularly like soap bubbles blown in a bowl.



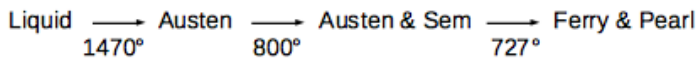
PHIXME Simulated "grains" (grains.png)

The structure of Austen is related to Ferry, whom we met in the Heavy Metal chapter.



FIGSME Body-centered cubic vs. face-centered cubic (ferryVSaust.png)

Ferry, as we learned, is *body-centered-cubic*: a frame with atoms at the corners and an atom in the center of the "body." This is steel's dominant personality at room temperature. But at the elevated temperature where Austen starts to form, this arrangement is not favored. Instead, Austen is *face-centered-cubic*. He also has atoms at the corners of a cube, but each "face" of the cube has an atom in its center while the middle of the cube is empty.² The Austen slush first appears at about 1470°C. As the temperature drops further, the metal solidifies entirely into grains of Austen, grains that are relatively soft.



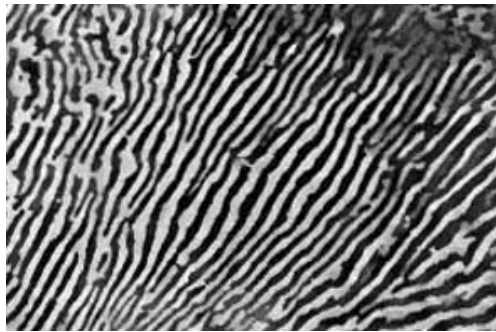
FIGSME Simplified progression of cooling steel (cooling.png)

While still hot, the Austen lattice can retain modest amounts of carbon. But as he cools, he can hold less and less. If there is a lot of carbon in the heat, and the temperature drops low enough, the carbon will start to squeeze out of Austen's

² In these graphics, I have omitted the carbon atoms that are tucked into the gaps between the iron atoms and that do, in fact, stretch out and distort the cubes.

cubes and form the Sem phase alongside of him. Sem is also an iron/carbon lattice, though one rather more complicated than Ferry or Austen.³ Sem can hold a lot of carbon, almost 7% by weight, while Austen can contain no more than 1%. Sem is hard but brittle, and he forms as small nodules within the Austen grains.

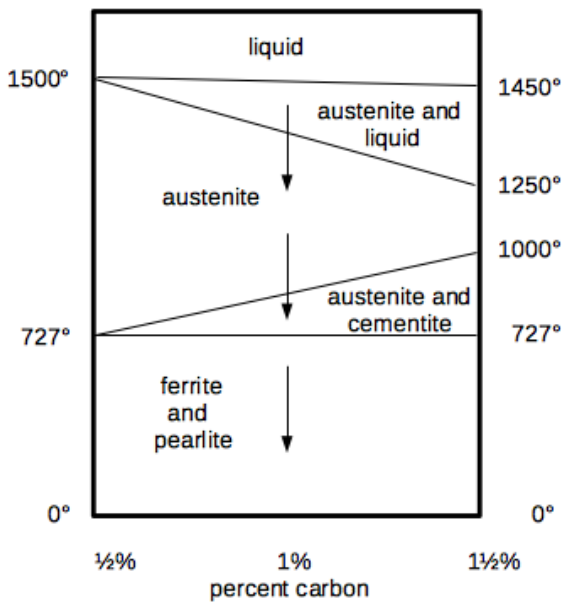
Alas for Austen, he will dissolve like a spring snowman. As the temperature drops below 727°C, he turns completely into the phases of Ferry and Pearl. The central iron atom in Ferry's body-centered cube leaves very little open space, so his lattice can hold only a smidgen of carbon. As Austen changes to Ferry, he spits out nearly all his remaining carbon atoms. They are incorporated into newcomer Pearl, who is made of alternating layers of Sem and Ferry, the former gobbling up Austen's ejected carbon.⁴ The Pearl grains also incorporate all of the Sem that had formed inside Austen, so that Sem no longer has an independent existence.⁵



FIGSME Pearl. Dark plates are Sem, light are Ferry. P. Barton, UC Santa Barbara (pearlite_ucsb.png PERMISSION)

Below is a simplified phase diagram for the transformations of our steel as it cools, and I will now introduce the proper metallurgical names of the main personalities: austenite, cementite, pearlite, and ferrite.⁶

-
- 3 Complicated enough that I will pass over the details.
 - 4 Pearl is not, herself, a lattice. She's just layers of Ferry and Sem.
 - 5 Sem gets very depressed about that.
 - 6 Pearlite is not to be confused with *perlite*, a mineral.



FIGSME Simplified phases of tool steel (after Carter). Arrows show 1% carbon cooling path. (steel_phase.png)

The vertical axis is temperature and the horizontal axis is the percentage (by weight) of carbon in the heat. Let's follow the 1% line: the heat starts out completely liquid above 1470°C. As it cools, it becomes a slush of austenite and liquid, and by 1350°C it's all austenite. At 800°C the austenite can no longer hold all the carbon; cementite begins to form, taking up the excess. As we cool past 727°C, the austenite structure can no longer be sustained and the lattice turns to ferrite, expelling lots of carbon that is assimilated into the ferrite/cementite sandwiches of pearlite.

The journey by which iron and carbon pass through different stages is somewhat akin to that of a deflating balloon. The atoms of iron have a powerful urge to form bonds. Likewise, the balloon's elastic skin wants to contract down to a minimal size. Air pressure spreads the rubber apart, while

temperature holds the iron atoms apart. As the liquid iron cools, the bonding force can assert itself more and more and the Austen and Ferry lattices appear, each having less "stretch" available between the atoms and less space for the embedded carbon.⁷

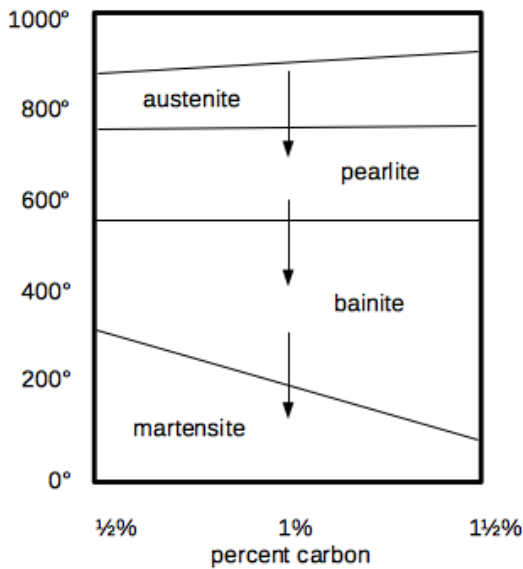
The room-temperature steel of Ferry and Pearl is what we get from the steel mill. It doesn't make very good tools because the carbon needed to fortify the iron lattices has been segregated into the Sem layers inside Pearl, where it doesn't help much. What to do? And what became of Marten?

* * *

When our metal was poured from the furnace it was allowed to cool *gradually*. This permitted the orderly progression from liquid to liquid/austenite to austenite/cementite to ferrite/pearlite. It takes time for the atoms to re-arrange themselves during these transitions, and a slow cool lets the dance proceed to completion. But what if we cooled the metal so fast that the atoms became sluggish and lost their mobility before assuming the next-lowest-temperature configuration? This can be done, and the trick is called *quenching*. Quenching freezes the atoms into an intermediate arrangement, a new phase that didn't exist in the above diagram. This way, we can stop the iron from falling all the way down to ferrite, and Marten (martensite) will emerge to give us the properties we need.

The technique of quenching was surely discovered by accident: some early blacksmith dropped a hot example of primitive steel into water. When the steam cleared, he found that his workpiece was wonderfully hard. For the quench to help us, we must first bring the metal back into the austenite phase, and we need an updated diagram to illustrate the new phase transitions. The phases in this diagram are those that arise when hot austenite is quenched at different temperatures.

⁷ Sem can absorb the excess carbon atoms because he incorporates them right into his lattice (they don't need to fight for space).

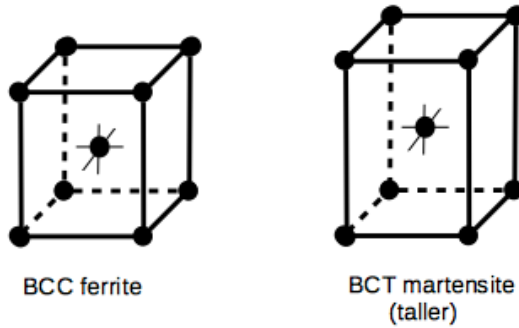


FIGSME Simplified phase diagram of austenite quenched at different temperatures. Quench path shown for austenite to martensite. (after Verhoeven) (quench_phase.png)

Now Marten comes onstage, and the minor character Bain appears.⁸ To harden, we must raise the temperature of the workpiece to about 900°C, converting the ferrite and pearlite to back to austenite. The piece is then thrust into a room-temperature liquid. As it speed-cools, the austenite skips directly to martensite, with bits of bainite possibly mixed in (and some residual austenite).

Martensite is another rectangular lattice, but not quite cubical like ferrite. The shape is *body-centered tetragonal* (BCT), meaning the building block is stretched in one direction, leaving space for more carbon. This is the hardened product needed for tools.

⁸ Bainite is another mixture of ferrite and cementite. Some bainite and some residual austenite may remain in the martensite.



FIGSME Ferrite vs martensite (bccVSbct.png)

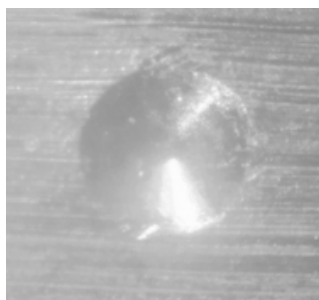
In the laboratory, hardness is measured with a penetration test. A small, extremely hard impactor of precise shape is driven into the test piece by a fixed amount of force. The hardness is evaluated as either the diameter or the depth of the resulting indentation. A *Rockwell* test, measuring the penetration depth of a diamond cone, was applied to four of Andrew's tools and, for comparison, a modern chisel.

tool	Rockwell "C" hardness
Ibbotson plane blade	55
Ward & Payne plane blade	62
Ward & Payne mortising chisel	55
Ward & Payne gouge	52
modern Ashley Iles chisel	58

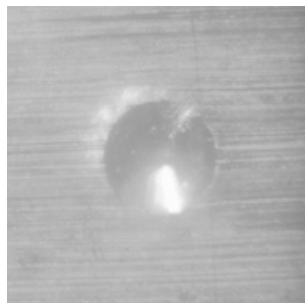
FIXME Rockwell hardnesses

The numbers on the Rockwell scale have no direct physical interpretation—higher numbers simply mean harder metal. There are multiple Rockwell scales (A, B, C, etc.), covering different hardness ranges. The Ashley Iles chisel is a premium woodworking tool from Britain. It has a C hardness of only 27

towards the handle but 58 at the cutting end. Below are images of two impact tests for this blade.



Rockwell C 27 near handle
about 1/2mm



PHIXME

(impact27.png, impact58.png)

Rockwell C 58 near tip
about 1/3mm

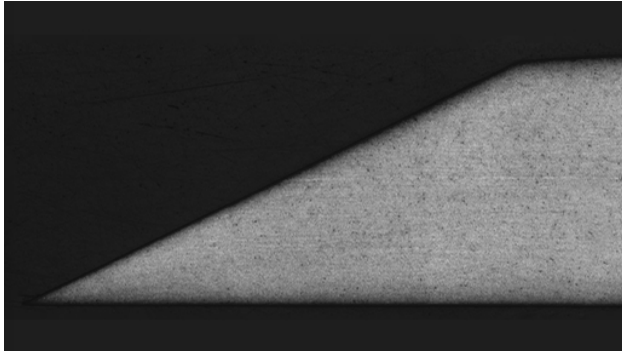


PHIXME Location of test points (ashleyRC.jpg)

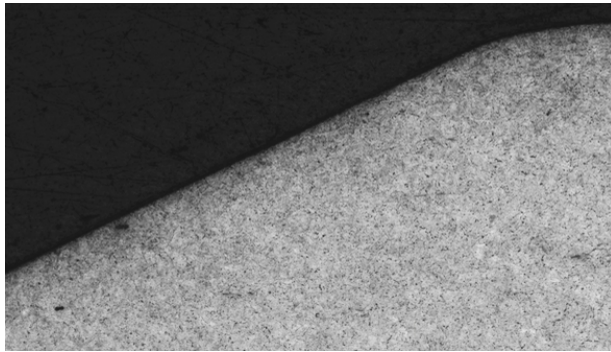
The Benson hammer also went under the Rockwell cone. The hammer face showed widely varying hardness at different points, from 25 to 58. This was likely due to uneven heating at the hands of the freshman metallurgist. Also, the head is the thickest part of the hammer, difficult to quench rapidly and evenly. Areas of locally low hardness account for the dents the tool has accumulated in use.

The actual grain structure of steel can be seen under high magnification, if one first polishes the metal and then etches the surface with a powerful acid. A friend cut end-slices from the Ibbotson plane blade, the Ward & Payne chisel,

and the Ashley Iles chisel for this purpose.⁹ Below are photomicrographs of the Iles chisel tip. The highly uniform structure is composed of martensite.



PHIXME Ashley Iles chisel tip (ashley1_mono.png)

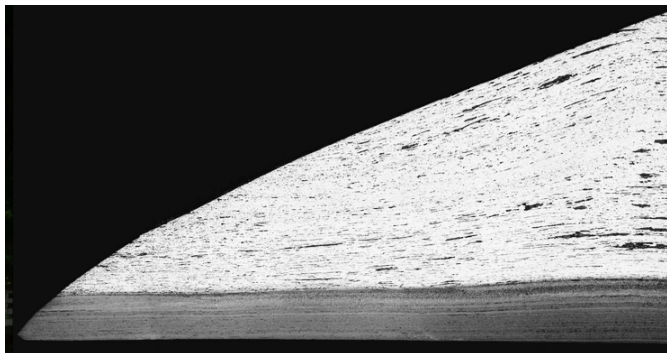


PHIXME Ashley Iles at higher magnification (ashley2_mono.png)

Here is the Ward & Payne mortising chisel:¹⁰

⁹ The metallurgical analysis was done by EAG Laboratories of El Segundo, CA.

¹⁰ A chisel for cutting deep sockets. We'll meet it in the next chapter.

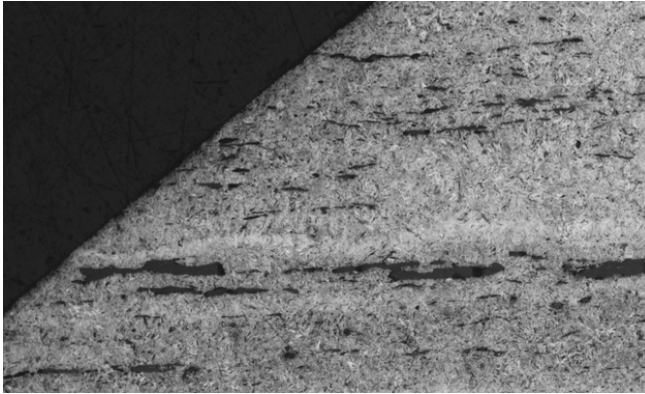


PHIXME Ward and Payne chisel (WP25_mono.png)

What have we here? Can you say "cost reduction"? The blade is a sandwich of tool steel on the bottom and wrought iron on top. A mortising chisel needs a hefty blade, but only the tip actually cuts wood. This chisel was made with a modest layer of steel to do the carving, while cheap iron provides the bulk structure needed to keep the blade stiff.¹¹ A modern furnace can crank out tool steel in abundance, but in Andrew's time the stuff was something of a specialty product. There was no point in using more of it than necessary. The visible contrast in the two materials is obvious, but remember that the steel is just iron made with a little bit of carbon and then subjected to hardening. Chemically, the two layers are not that different. They were fabricated separately, then hot-hammered together to make a unit.

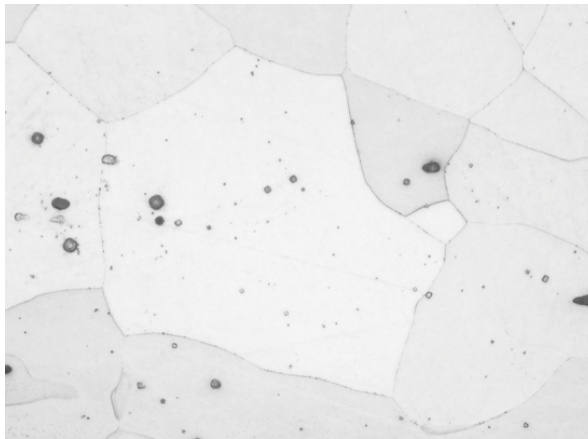
In the iron we can see large *inclusions*: bits of slag from the furnace. The martensite layer, below, is much cleaner than the iron, but not as pure as the modern steel of the Ashley Iles.

11 The C 55 hardness, above, was measured on the steel. The wrought iron is so soft that it can't be evaluated with the C test.



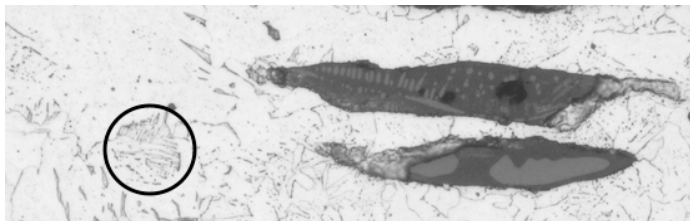
PHIXME Martensite with inclusions in Ward & Payne blade (WP100_mono.jpg)

The wrought iron is composed of ferrite, and the grains show up nicely in the Ibbotson plane blade (another iron/steel sandwich):



PHIXME Ferrite grains with inclusions in Ibbotson wrought iron (ferrite_mono.jpg)

Where the layers of iron and steel meet, one can also see some pearlite:



PHIXME Interface between iron and steel. Pearlite circled. (pearlite_mono.jpg)

Martensite is a good material for wood chisels, but quench-hardening can be *too* effective for other kinds of tools. The steel becomes brittle. It has no toughness and will break easily.¹² This problem is solved by *tempering*: a third, more modest journey on the phase diagram.

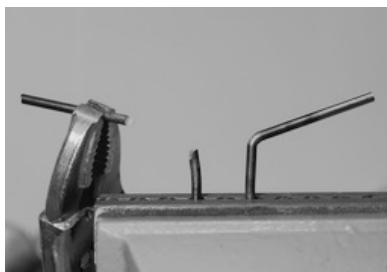
The objective of tempering is to relax the martensite a bit. The strain of holding so many carbon atoms leaves the martensite lattice with little tolerance for shock. By tempering, we give the stretched tetragonal structure a chance to release some carbon and assume a shape that's closer to body-centered-cubic. To do this, we heat the workpiece gently, perhaps as high as 450°C. This is not enough to effect a wholesale phase change, but it does allow some martensite to convert into ferrite and cementite. The ferrite is agreeably soft, giving the metal some resilience. Meanwhile, the cementite has its own salutary effect: this material is a kind of *carbide*. It has great resistance to wear, as users of carbide saws know. The tempering process does cost us some hardness, but we get a less fragile tool.¹³

John Verhoeven, in *Steel Metallurgy for the non-Metallurgist*, has a nifty demonstration of tempering using "drill rod," a form of tool steel. You take two lengths of rod and heat the middle section of each to the austenitizing temperature, then quench to make a region of martensite. Then clamp one rod in a vise and bend it sharply in the middle. The very hard but untempered section will snap.

12 A joiner who ran his plane blade onto a nail faced an extended session with the grindstone to eliminate the resulting notch.

13 At Benson, we didn't temper our hammer heads. The C 58 (maximum) hardness is high for a hammer.

Next, take the other rod and reheat it gently with no quench.¹⁴ Let it air-cool and mount it also in the vise. It will yield to a strong turn of the pliers without breaking. This remarkable difference was brought about by simply releasing some carbon from the martensite.



PHIXME austenitizing the two rods together bending: tempered rod on right
(temper1.jpg, temper2.jpg)

I got an accidental demonstration of the effects of hardening. After the end of the mortising chisel was chopped off for analysis, I had to form a new slanted tip that could be sharpened. Using a hacksaw, I cut down through the wrought iron and into the steel. The saw—even with a fresh blade—simply would not go through the hardened lower layer of the shaft. I had to break off the hanging piece with a Vise-Grip so the face could be re-ground.

¹⁴ Before the advent of modern instruments, metallurgists used color to infer the temperature of hot metal. The hue I looked for was a dark blue, corresponding to only about 315°C.



PHIXME Thwarted cut at lower right (sawed_blade.jpg)

This is why padlock shackles are made of hardened steel!

The Tools Go Back to Work

I had long wanted to make something with Andrew's tools, something he would have built himself. The surviving implements are far from a complete set. There are no hammers, mallets, or saws. Some planes and plane irons¹ are missing, as is the brace for the drill bits. There is only a single, small square and one very large screwdriver. All told, about fifty artifacts remain. They can be broadly divided into the following categories: carving, shaving, drilling, and measuring and marking. The best assortment in the collection is of carving tools—chisels and gouges.² Most of the wooden tool handles have been stamped, "Aw Calderwood."³ FIXME TYPOGRAPHY



PHIXME A selection of the chisels and gouges (chisels.jpg)

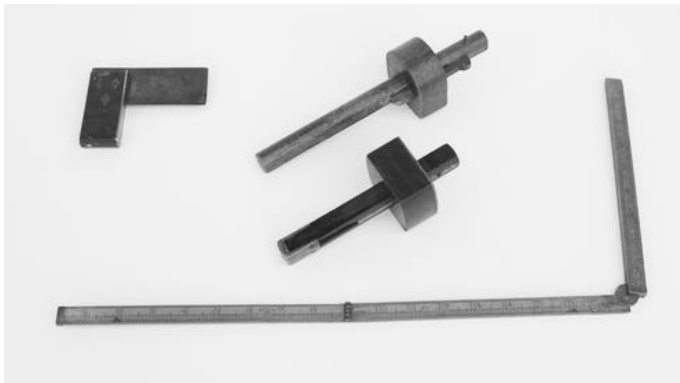
1 The blade of a plane is called an "iron."

2 The former have flat blades for straight cutting, while the latter are curved for ornamental work.

3 With his ownership so indicated, Andrew could have insured the tools.



PHIXME Bits and gimlets for drilling holes (bits.jpg)

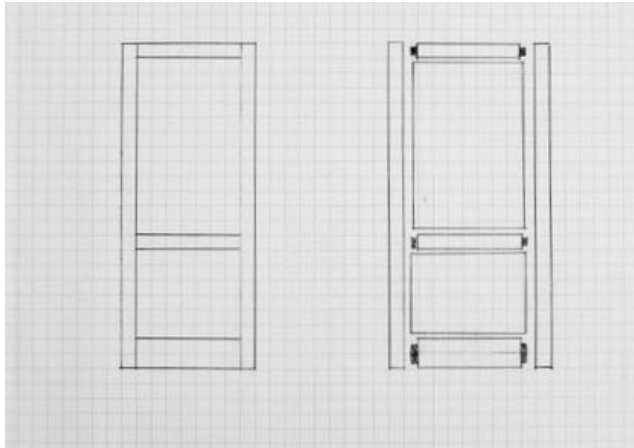


PHIXME Square, rule, and gauges (measure.jpg)

I settled on a two-panel door as a project.⁴ A panel door has an exterior frame surrounding some number of thin interior panels, the panels being divided by additional framing. Vertical framing members are called *stiles*, while the horizontal members are *rails*. My own frame would be of walnut, and its construction would entail 1) rough-cutting the pieces to length and width, 2)

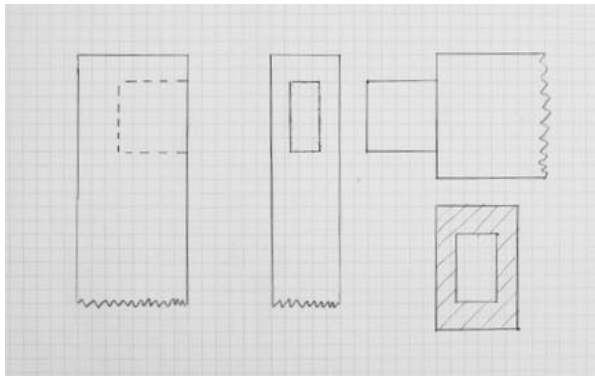
⁴ I am no craftsman. Experienced woodworkers may wish to procure a supply of antacid before reading further.

"milling" them to final dimensions and smoothness, and 3) cutting the interlocks needed to hold the final product together.



FIGSME Panel door assembled (left) and exploded (explode.jpg)

The panels are held in the framing by grooves, and the rails and stiles are held together with mortise-and-tenon joints. These joints are of some interest, for proficiency in making them was an essential skill of a joiner. No screws, nails, or modern "biscuits" are used. Glue and close-fitting wood make for a structure that is strong and durable.



FIGSME Side and front views of mortise (left) and tenon (cutaway.jpg)

The mortise, or pocket, of the joint is made with a specialized chisel, of which four have come down to me.



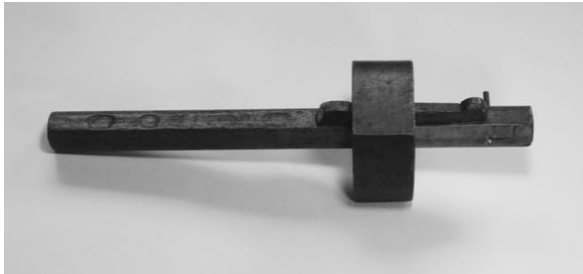
PHIXME mortising chisels (mortchisel.jpg, mortchisel2.jpg)

Mortising chisels are narrow, with squared-off sides. They come in standard widths, Andrew's being 1/8", 1/4", 3/8", and 1/2".⁵ With the assistance of a mallet, they will excavate a deep, straight trench that becomes the mortise. The tenon, by contrast, is made with a fine-toothed saw, cutting away just enough material so that the remainder fits snugly into the mortise. When the mortise and tenon interlock, they are in contact over a considerable surface area. Glue applied over the mating surfaces has a large foothold and, along with some swelling of the wood, achieves an iron grip.

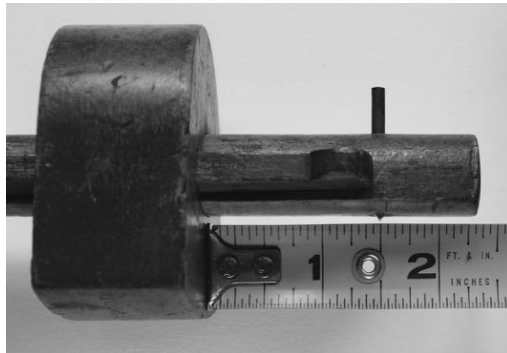
Clearly, proper laying-out of the locations and dimensions for both mortise and tenon is essential for making a good joint. In principle, a straightedge, square, ruler, and pencil could do the job, but this four-way combination of tools creates opportunities for small inaccuracies to creep in—risky for critical work. The joiner would use *gauges* to draw the lines for his saw and chisel to follow. Andrew's collection has two such implements: a *marking* gauge and a

5 Today, the big chisel is fondly called a *Victorian Pigsticker*. I took it to Rockler Woodworking in Cambridge, Massachusetts, and showed it to "Woody," their expert on old hand tools. Holding it reverentially, he turned to his co-workers and said, "I'm having a religious experience!"

mortising gauge. A marking gauge consists of a small beam holding a sharpened pin (mounted crosswise at one end) and a block that can be adjusted along the length of the beam and locked in place. The joiner sets the distance between the block and the pin for the width of wood he wishes to cut off. The block is held against one face of the wood piece, and the beam is pulled along the length of the adjoining face, the pin scribing where the cut is to be made.



PHIXME Marking gauge (mark1.jpg)



PHIXME Setting the mark distance (mark2.jpg)

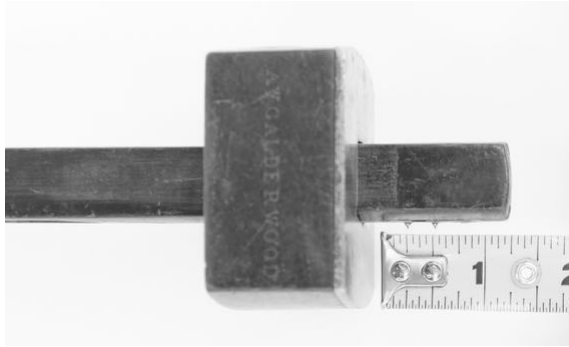


PHIXME Preparing to scribe the tenon depth (mark3.jpg)

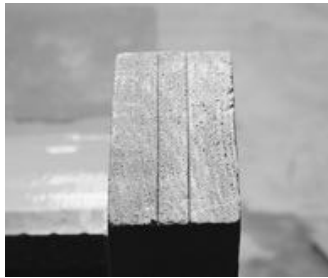


PHIXME Tenon depth line (mark4.jpg)

The mortising gauge has *two* pins on the beam, one fixed and the other adjustable. The distance between the pins is set via a screw to match the width of the mortise, and the block is set so as to place the mortise marks at the right distance from the wood edge. Once set, the same gauge is used to mark both the exterior lines of the tenon and the interior lines of the mortise. The beauty of the gauges is that, once set, they will mark each frame joint consistently, without the joiner expending any special care to see that they are all the same.



PHIXME Setting the pins of the mortising gauge (gauged.jpg)

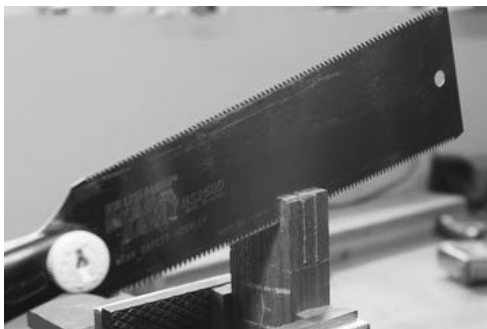


PHIXME Main cut-lines of tenon as scribed (mort3.jpg)

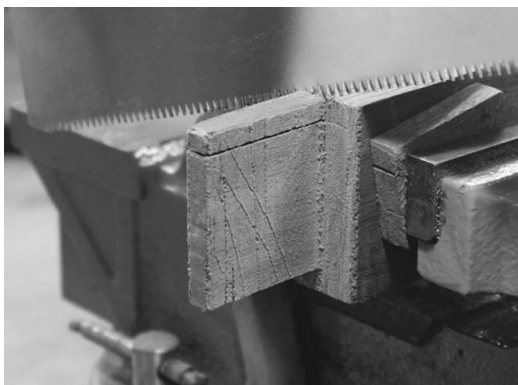


PHIXME Vertical cut along main lines (tenon1.jpg)

Tenons have shoulders on either side, where a horizontal cut is made to trim off the "arms," if you will.⁶ My tenons also had a shoulder on each end, so crosswise vertical cuts were needed. Ideally, I would have had a second marking gauge that I could set for the positions of the shoulder cuts, but I had to use a ruler and square to mark those lines.

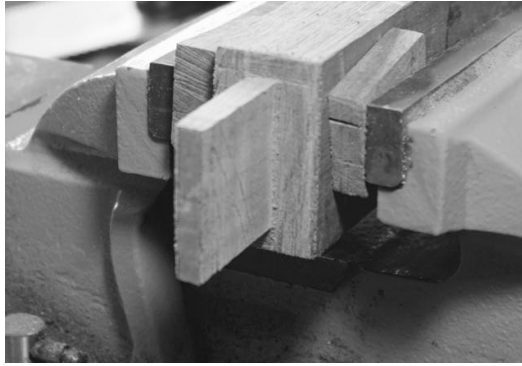


PHIXME Crosswise shoulder cut (tenon2.jpg)



PHIXME Trimming the "arm" off the end shoulder (tenon4.jpg)

6 Think of the tenon, itself, as the "head" and the arms being raised high.



PHIXME Rough-cut tenon (tenon5.jpg)



PHIXME Cleaning up tenon with a chisel (cleanup.jpg)

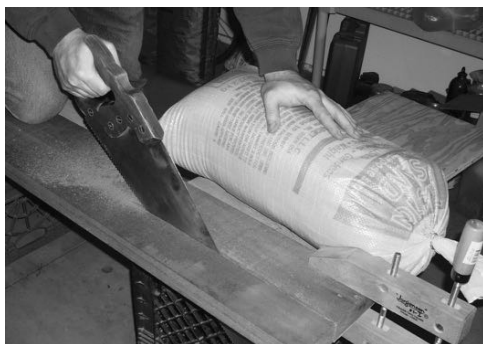
* * *

But I've gotten ahead of myself. Joint-making happens deep into the project, not at the beginning. Andrew would have started a door by going out to his woodyard and choosing stock for the rails and stiles. The lumber at hand would have been seasoned but raw, with uneven thickness, rough surfaces, and sides that were not square to each other. Today we have machines to mill raw lumber to uniform shape and smoothness and cut it to exact size, but Andrew would have done all that work by hand. When I started on the door, I was taking a woodworking class where I had access to power equipment, but I resolved to

do much of the preparation the historical way. The first task was to saw my timber into the approximate sizes for the framing. Using the marking gauge, I scribed my walnut stock into approximately three-inch-wide lengths, then hand sawed two stiles of about five-foot length. It was a lot of work.



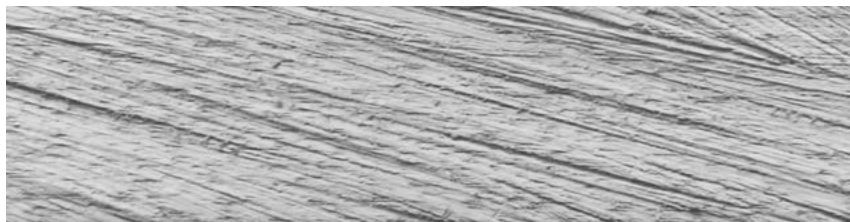
PHIXME Marking the stile width (milling1.jpg)



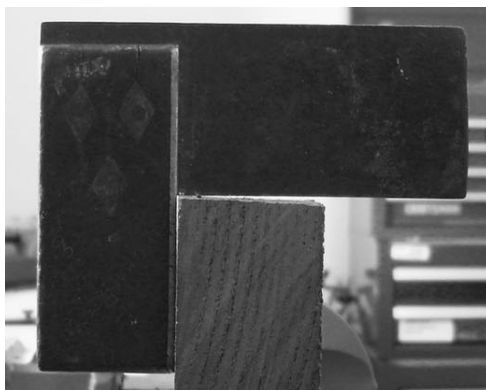
PHIXME Sawing a stile. Sandbag holds a board to which the stile stock is clamped.
(milling2.jpg)

The three rails were each of different widths, and much shorter than the stiles. Cutting them was a comparatively small task. The rip saw I used, with an aggressive blade for fast work, did not, of course, leave a clean edge to the

boards, nor could I hold it exactly vertical to make the cuts square to the board faces.



PHIXME Edge left by the saw (milling3.jpg)



PHIXME Edge not square to face (milling4.jpg)

Since I also didn't draw the saw perfectly straight along the cut, the edge was a bit "wavy." Before anything else could be done, the edge had to be made flat and smooth (I cut all my pieces with extra width that could be shaved off to eliminate these faults).

If one tool is emblematic of Andrew's trade, it must be the plane, for Mayhew wrote, "*...all which the plane passes over is joiners' work.*" At its simplest, a plane consists of a cutting blade held at an incline inside a block having a flat lower surface. The blade, extending just below the bottom, shaves off thin

cuttings as the body is repeatedly pushed forward across the workpiece. Planes come in two general flavors: those for smoothing and thinning, and those for cutting profiles (such as mouldings and rabbets).



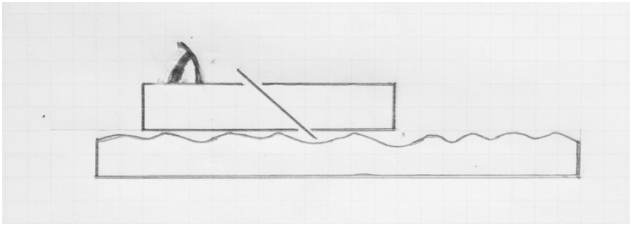
PHIXME Try-plane and smoothing plane (planes.jpg)

And so I put Andrew's planes to the task of milling my rough stock. A joiner would possess a number of planes, for work of varying fineness and for special situations. For cleaning up my rail edges, I began with a *try plane*, a wide-bladed tool with a long body.



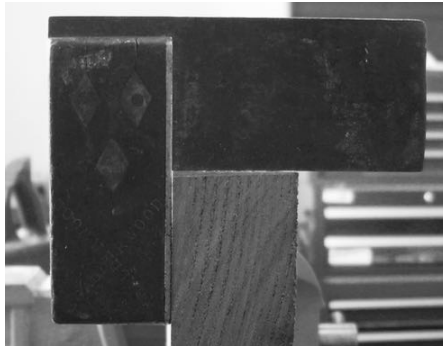
PHIXME Try plane at work on an edge (milling6.jpg)

The long body of the try plane makes the tool relatively insensitive to hills and hollows in the surface. The bottom of the plane, resting on an extended stretch of the workpiece, doesn't jump up and down much, so the blade is able to make relatively flat cuts that gradually bring the high spots down to a level.



FIGSME Try-plane on rough surface (lowpass.jpg)

After the raggedness has been taken out of the wood, one switches to the smaller *smoothing plane*, wielded more gently to finish the job. Repeatedly checking the surface with a square and straightedge, you locate the high spots to shave down and are eventually rewarded with a nice edge.



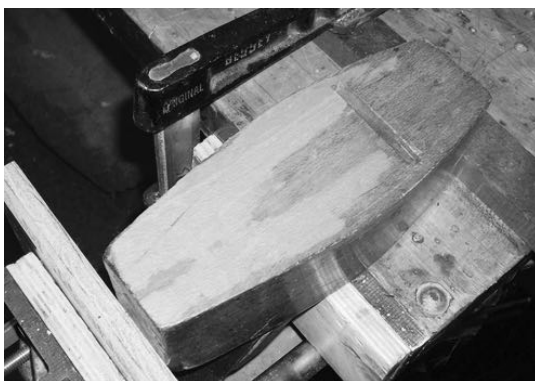
PHIXME Edge squared after planing (milling7.jpg)

But before I could put the smoothing plane to work, I faced a trial of frightening severity: *planing* the plane. After years of use and then decades of

storage (in non-humidity-controlled environments), the sole of Andrew's plane was no longer flat. If I wanted to use it, there was no choice but to take another plane and even out the surface. The woodworking class instructor assured me that this was a standard procedure, but I trembled at the thought I might wreck an irreplaceable heirloom. The patient was duly clamped upside-down to a bench and a sharp modern plane applied.



PHIXME Smoothing plane held by the bench vise and an improvised "stop." (gulp!) (smooth2.jpg)



PHIXME Shaved! High and low areas evident after one pass. (smooth3.jpg)



PHIXME Final surface (smooth4.jpg)

The operation was a success.

After one edge of a workpiece has been satisfactorily milled, it is next planed to thickness. The marking gauge is adjusted for the desired thickness and a line is scribed upon the newly-cleaned edge. The face of the board can then be planed down to the line.

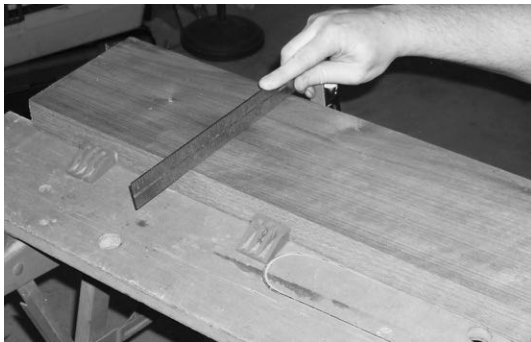


PHIXME Marking the thickness along edge (thick1.jpg)



PHIXME Planing down to the line (thick2.jpg)

As one proceeds, a straightedge is used to verify that the surface is flat from side to side.



PHIXME Checking flatness across the width (milling8.jpg)



PHIXME Milling a stile (stile1.jpg)

Rails, being short, are fairly easy to mill. Stiles are more work and more susceptible to *winding*. While a board can have uniform thickness from one end to the other, and its surface can be fairly flat in cross-sections along its length, it can still be twisted, or *wound* as the old joiners would say. This defect is detected with *winding sticks*: a pair of matched rectangular wood pieces, each of whose long edges are completely flat and parallel. The sticks are placed some distance apart along the length of the piece being milled, and the woodworker sights along the top of them, one stick viewed in front of the other. If the two top edges can be seen in perfect alignment, the surface is not twisted in between them.



PHIXME Winding sticks on the plane (wind1.jpg)



FIGSME Sightline across front and rear sticks (wind2.jpg) [REPLACE PHOTO WITH FIGURE]

I first used winding sticks when flattening the plane. They belonged to the class instructor, and were large enough for checking a much wider surface. I later improvised my own pair of sticks from angle iron, and they saw a lot of use on the stiles.



PHIXME Angle-iron winding sticks on a stile (wind3.jpg)

With one side and one edge finished, the rest of the workpiece can be milled to flatness, squareness, and final dimensions.⁷ In a modern shop, all of this work would have been done with a table saw (that cuts close to final width), a planer machine (that shaves close to final thickness), and a jointer (that gives perfectly square sides with a dead flat finish). One edge of one of my raw stiles was so far out of true that, in the interest of efficiency, I used a jointer to clean it up.

The try and smoothing planes are, by far, the most visually interesting of Andrew's tools. Besides sporting attractive, antique finishes,⁸ they are marked with the names of both their maker and retailer. They were made by the McVicar company, of Perth in central Scotland, and sold by John Dobie, 205 Argyle St. in Glasgow.⁹ The stamps of McVicar and Dobie can just be made out in the following picture of the nose of the smoothing plane.



PHIXME Dealer and maker stamps (nose.jpg)

Besides the stamps, there are a number of indentations on the nose. The tail of the plane has even more dents—obviously made with hammer blows. That's how Andrew fine-adjusted the blade depth. A modern plane will have a jackscrew for moving the blade up and down, or a quick-release clamp that permits the blade position to be tweaked and then locked. But the blades in

7 In addition to flattening and squaring, one must also eliminate bowing in the piece, a process I have not described (left as an exercise for the reader).

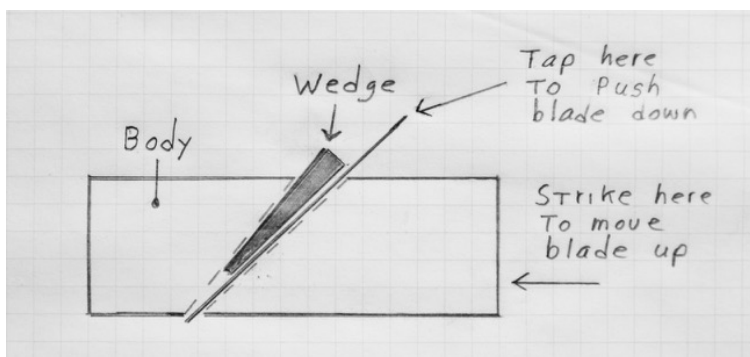
8 See color plates.

9 The 1868 Glasgow city directory lists Dobie as "Ironmongery, cutlery, saw, edge tool, plane, and file warehouse." [An ironmongery was a hardware store.] The 1862 directory of Perth locates "planemaker" George McVicar at 21 King St.

Andrew's planes are held in place with a wedge, and that presents a challenge: if the blade is first positioned at the desired depth, driving the wedge tight will move the iron an unpredictable amount deeper into the throat of the plane. What to do?

Well, when first inserting the blade, we locate it high enough in the throat so that the wedge will not drag it too far down. After seating the wedge, one can tap the back edge of the blade with a hammer to drive it to the desired depth. So far so good, but what if the blade goes in too far? We can move the blade back up with a variation on the parlor trick of yanking a tablecloth out from under the place settings.

Imagine a table with a thin plank of wood for a cloth. Rather than pulling it out from the front, we perform the trick by giving the plank a sharp hammer-hit from behind. It sails off of the table, leaving the plates, cups, and silverware in place. Just so, if we rap the tail of the plane, the body and wedge travel forward, but the blade, because of its inertia, will tend to stay put like the place settings. This makes it climb up the inclined throat of the plane, reducing the cutting depth.¹⁰ It really works!

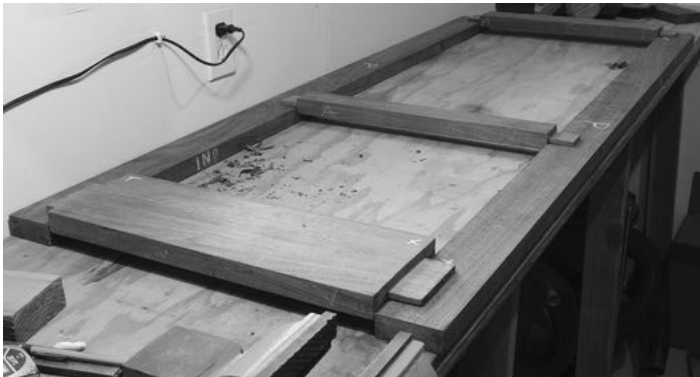


FIGSME Adjusting blade depth (adjust.jpg)

¹⁰ Of course, the blade, being wedged in place, is far from completely free to move, but it will shift a *little*, and a little is usually all we need.



PHIXME Dented tail of smoothing plane (tail.jpg)



PHIXME Checking rail spacing before cutting mortises (door01.jpg)

But back to mortises and tenons. After milling the rails and stiles, I actually set aside the door project for some time before making the joints. I practiced

cutting tenons again in the hope that I would not then butcher the real job too badly.



PHIXME Remnants of tenoning practice (practice.jpg)

I also practiced carving mortises.



PHIXME Test mortises (test_mortise.jpg)

The chisel had to be sharpened beforehand, and I did the final honing on Andrew's own stone.



PHIXME Honing Andrew's 1/4" chisel on his stone (hone.jpg)

Then I went to work...



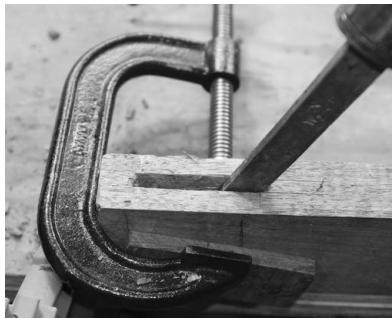
PHIXME mortise laid out (mortise0.jpg)



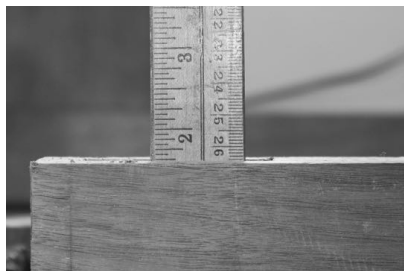
PHIXME Clamp keeps wood from rupturing out the sides (mortise1.jpg)



PHIXME Hammering away (mortise2.jpg)

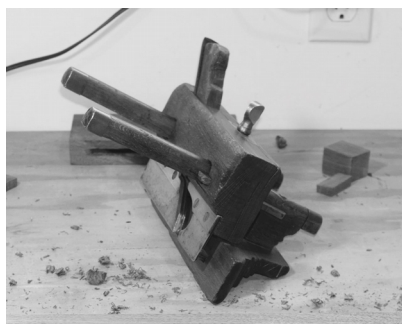


PHIXME Getting close (mortise3.jpg)

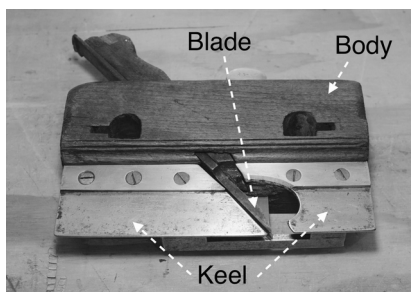
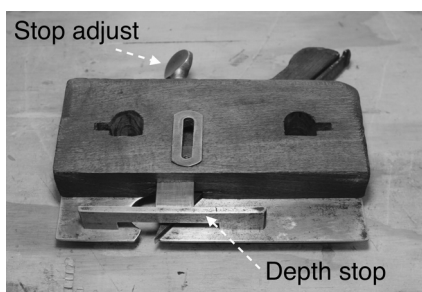


PHIXME Final depth (mortise4.jpg)

With the joints cut, it was time to turn my attention to the panels. In a traditional door, several thin boards of moderate width would be glued along their edges to make a panel wide enough to fit the framing. With the tools, wood, and skill at my disposal, that was not a practical path. I opted, instead, for birch plywood, an attractive material that could be purchased in sizes large enough to cut directly into the necessary sizes. But this shortcut did not exempt me from cutting grooves into the framing—grooves that would hold the panels in place without screws or even glue. This job would be done with a specialized tool.



PHIXME Plow plane with fence attached (plane3.jpg)



PHIXME Plow plane without fence, left and right-hand sides (plane1.jpg, plane2.jpg)

The planes used so far have had wide blades and perfect freedom to range over a wood surface. Grooving a frame calls for a very narrow blade held in a

controlled position. A *plow plane* is the answer. Andrew must have had a plow but it does not survive, so I bought one.¹¹ The plow plane, above, has a 1/16 inch metal "keel" that extends far below the wooden body. The keel is in two sections, and the back of the blade rests against the inclined front of the rear keel for support. Next to the keel is a "stop" that slides up and down, adjusted by a thumbscrew. The stop controls the depth of cut; it is gradually raised as the job proceeds, letting the blade go farther into the wood. The keel, being narrower than the blade, slides in the groove as the cut gets deeper. In principle, this particular plow could cut a groove one inch deep.

Taking the tool in hand, I soon discovered that the edge grain of my walnut was not conducive to planing. An experienced woodworker would have chosen his materials more carefully, leaving these particular timbers for other purposes. No matter how cautiously I advanced my depth of cut, the plane might start chattering down the groove, leaving tear-outs in its wake. Some time before, I had decided that there would be a "presentation" side of the door, upon which I would labor to do my best, letting the chips fall where they might on the other side. This now became not just an expedient but a necessity.¹²



PHIXME Plowing. Fence holds blade in center of workpiece. (plane5.jpg, plane6.jpg)

My grooves were only about 1/8" deep and somewhat irregular, meaning that the edges of my panels would need to be *very* straight so as not to leave gaps. Therefore, I availed myself of a table saw to do the cutting (sorry, Andrew).

-
- 11 While Andrew's tools are precious, they are not rare. There is an active community of antique tool users and collectors who sustain a ready market for similar implements. I did use one of Andrew's blades in the plow.
- 12 Apparently, I also had the plane blade wrong-side-up. There is a woodworking saying to the effect of, *If the Queen won't see it, don't worry about it*. Ergo, Your Majesty, don't open this door...

With the application of some stain on the panels and urethane on everything, the pieces were ready for assembly. Andrew, working with animal glue, would need to act very fast during glue-up, and the extra hands of apprentices would come in handy. Modern woodworking glue is far more time tolerant, and I could handle assembly on my own.



PHIXME Final check of fitting before staining the panels (finalfit.jpg)



PHIXME Clamping of the glue-up (glueup.jpg)

I had the luxury of making up my door's dimensions as I went along, permitting me to slice off some mistakes along the way. The joiners in the Calderwood shop would have worked to specifications, but likely not from

measured drawings—that is, scaled-down renderings (on paper) with the true dimensions indicated. Instead, they probably used full-size diagrams, called *rods*, drawn on thin wood panels. For nearly-flat projects like a door or window sash, the rod would give only side and top views, or, in the draftsman's lingo, vertical and horizontal *sections*. Once my door was finished, I drew a rod for it.



PHIXME Joiner's rod for the door, with top and side sections (rod1.jpg)

The final result? Well, nothing that would win any prizes. It took me a tremendous amount of time to make what would only pass for the work of a first-year apprentice.

But then, I'm only a first-year apprentice.

Keeping it in the Family

John Calderwood, father of Andrew and his eldest brother Alexander, died in 1895, leaving an estate worth £3293. Alexander, who had partnered with Andrew to run the joinery shop after John retired, died in 1902, leaving his own considerable estate of £2656. But when Andrew's own family crossed the U.S. border in 1908, they had the combined equivalent of only about £156.¹ What *happened*? Even allowing for the cost of travel, Andrew had left Scotland with mere crumbs of the Calderwood wealth. The hard clues I can find on this point come from records of property taxes and probates.²



PHIXME Andrew (left) and Alexander in Scotland (Alex_Andrew.jpg)

Real estate in Scotland was assessed annually for taxation, based upon the rent it could command. Copies of the assessments are preserved in the National Records in Edinburgh and the documents for 1855, 1865, 1875, 1885, 1895, 1905, and some years beyond have been scanned and indexed and are

- 1 \$750 cash. I do not know if emigrants ever carried anything like a letter of credit backed by assets still held in the Old Country, but the family's circumstances upon reaching the United States do not indicate that there was any significant store of additional money available to them. They got jobs right away, and not cushy ones.
- 2 Probates were actually known as *successions*.

accessible over the Internet.³ For each property, there was a Proprietor, a Tenant, and an Occupier (potentially different from the first two). An individual's trade was often identified in the record. Below is a simplified example from East Kilbride in 1865:

#	description	location	proprietor	tenant	occupier	rent	feu-duty
39	house, workshop, yard	Kirkton	John Calderwood, wright	-	John Calderwood	£22	£4 1s 9p
39	house	Kirkton	John Calderwood, wright	James Talsey	James Talsey	£5 16s	£0 6s 3p

FIXME Example Valuation Roll entries (1865)

The assessed rent (not necessarily the as-paid rent) was recorded, along with a medieval holdover called the *feu-duty*. At this time in Scotland, land was still held by "feudal tenure." The monarch delegated control of territory to vassal persons or institutions, who could further delegate down the social ladder. Those on lower rungs might have an obligation to those above. In medieval times, this obligation was for military service. In Andrew's time, it was for an annual fee.⁴ The feu-duty was paid by the proprietor, and the taxes were paid one-half by the proprietor and one-half by the tenant and occupier.

I was able to view family land holdings from 1855-1905, but the properties are not easy to trace from one year to the next. For starters, most of the rolls are recorded in longhand and not always easy to read. More importantly, the properties did not have permanent identifiers like modern American tax lots, the parcels having different numberings in each year. Multiple small holdings under the same proprietor might be lumped together in one year, then itemized in another. It was considerable work to track Calderwood real estate over the decades.

In 1855 John Calderwood was the owner of a house and workshop. Ten years later, he had a second house (shown in the above example). By 1875, he was also leasing much of a field around the first house and its workshop. In 1885, John still owned the second house, but had sold the house/shop property to

3 <https://scotlandspeople.gov.uk>

4 Scottish feudal tenure was finally abolished in 2004.

Alexander. From the table below, one can see that rents steadily increased from '55 to '85.

property	1855	1865	1875	1885
house and shop	£15	£22	£28	-
second house	-	£5 16s	£8	£18

FIXME rated rents for John's properties

The valuation rolls show Andrew only ever owning one property, that being John's second house from the 1865 roll, probably purchased from his father in 1886. Alexander's holdings, below, were rather more substantial.

year	description	rated rent
1865	1 house	£ 14
1875	4 houses	£ 75
1885	9 houses workshop & land	£132
1895	11houses, workshop & land and 2 land parcels	£155

FIXME Alexander's property table (shillings rounded to pounds)

Alexander had amassed considerable property as early as 1875⁵—where did he get the money for it? Inheritance would be one possibility. His father would actually live until May of 1895, but let's look at the major provisions of John Calderwood's 1872 will:

- *Sell all "means" and heritable estate and divide the proceeds evenly among the children.*
- *Oldest son, Alexander, to have the option, at price of £600, to buy the house, workshop, and woodyard, and to also have the option to buy the stock-in-trade. Younger children, in their turn, to have the same option if Alexander declines.*
- *Second son, Robert, to have the option, at a price of £70, to buy John's second house, then occupied by John's mother. Younger children, in their turn, to have the same option if Robert declines.*

5 He was also serving as a representative or agent for thirteen other properties.

- *Outstanding loans to the children, totaling £2640 in cash and goods, were to be handled as assets of the estate.*⁶

Scottish inheritance law distinguished between two types of property: moveable and heritable. Moveable property was anything that could literally be moved, such as furniture, tools, cash, as well as investments. Land and buildings, in contrast, were heritable. At the time the will was composed, Scottish succession law had recently undergone a major change. For generations, the law of primogeniture had applied to heritable assets: they all went to the oldest son, and the widow and younger children were left with the moveable estate.⁷ In 1868, primogeniture was abolished, except for cases when the deceased died without a will. John's own father would have had no say in how his land was distributed at his death—it would all go to John. Under the new law, John was free to direct that his own heritable estate be sold and the proceeds divided.

Two codicils were added to the will in 1886. The first stated that the second house had been conveyed to Andrew, so the provisions in the will for that property were void. The second codicil acknowledged that the joinery business had been conveyed to Alexander and Andrew.⁸ It was also noted that Alexander and Andrew had made no payment for "good will,"⁹ and that the transaction included no benefit for John Jr., who had assisted in the shop for years. Accordingly, the codicil directs that interest on any unpaid debt John Jr. owed to his father's estate was to be canceled.¹⁰ At John's death in 1895, his executors compiled the following inventory of moveable assets:

-
- 6 At that time the cash loans were as follows: Alexander £450; John £460; Robert, David, Andrew, and George £300 each; Janet and Mary £100 each. And to Alexander and Andrew, a further £330 worth of stock-in-trade.
 - 7 Even then, the oldest son also got his choice of farming implements and household furniture. Part of the moveable estate could be bequeathed to persons outside of the immediate family.
 - 8 The 1872 will stated that John had *retired* from the business, but he apparently still owned it.
 - 9 Apparently the brothers only paid for the physical assets of the firm, and not for the intangible value of the Calderwood name in business.
 - 10 The original will also stated that loans to the daughters incurred no interest.

item	£ s d
cash in house	2 0 0
furniture, possessions	27 18 6
gas company stock	60 5 0
bank deposits	282 10 0
loans due from children	2920 1 6
total	3292 15 0

FIXME John Calderwood's moveable estate

In the 1895 valuation roll, I do not see John owning any property. The succession report by John's executor showed loans then due from children were ~£820 from Alexander, and £300 each from Robert, David, John Jr., George, Andrew, Janet, and Mary. Dividing a £3293 estate among the eight children (John Calderwood was then a widower), each was left with approximately £410. Everyone but Alexander would have received a net £110, while Alexander would have owed £410.

If, at his death, John still held a house,¹¹ it would have been sold and the proceeds evenly divided. There are no records of actual property values available, only of rents. One can, however, make a crude estimate of the relation between rent and value by looking at the house mentioned in the original will, the house that John likely last occupied. It was stated that Robert had the right of purchase for £70. That was in 1872. The 1875 Valuation Roll placed the rate at £8, while the 1865 roll placed it at £5 16s, implying an 1872 rent of about £7 6s.¹² This would indicate annual house rents as being very roughly 10% of the property value.

By 1885, the rate on the house had risen to £18. From 1885 to 1895, rents on other properties appeared to be stable, so it is not unreasonable to assume that the house in question was still rated at £18 at John's death, implying a value of

11 Since John Sr. died during compilation of the 1895 Valuation Roll, the situation is a bit murky. It is possible that what property he had was sold between his death in May and the final version of the Roll that came out in September. Such property would likely have consisted of only the house he lived in.

12 Compound annual growth of about 3.3%.

£180. Adding this amount to the moveable estate would not substantially increase the size of the individual bequests. Overall, it appears that John disposed of his estate largely in advance, by loaning the wealth to his children.

John would not have inherited great wealth from his own father, another Alexander.¹³ That succession, in 1868, took place under primogeniture, but in 1865 the elder Alexander appeared not to have any heritable property. Thus, it seems that John built up his own wealth through his own business, which offers us a clue about the relative prosperity of Andrew and his eldest brother. The conveyance mentioned in the 1886 codicil implies that Alexander and Andrew were then partners in the business, but were they equal partners? The original will clearly gave Alexander first claim on the joinery shop. I speculate that Andrew was a minority partner, perhaps with only a modest stake that could not support the family he came to have. By 1889, Alexander was sole proprietor, while Andrew was a tenant farmer with few economic prospects.

When John Calderwood was planning his bequests, primogeniture was gone in the eyes of the law, but it may have remained the social custom. I think Alexander got preferential loans from his father, certainly for buying the business and maybe for buying real estate, and was thereby enabled to build his own modest fortune. Even if this particular scenario was not the case, it's safe to assume that John saw to it that Alexander got the family jewels. I say this because my father remembers *his* father complaining about Scotland: how the eldest son got the wealth and the other children got nothing.

The economic disparity between Alexander and Andrew is even greater than I have laid out so far, for the asset inventory at Alexander's death did not include his real estate.¹⁴ Seven years prior to his demise, the holdings were as follows:

13 The records are confusing. In the succession paperwork Alexander is listed as a "Grocer and Spirit Dealer," but other documents have him as a farm overseer. The estate was worth about £540. I do not know how many ways it was divided.

14 Alexander died "intestate"; there was no will laying out his assets and their intended distribution.

Property	Tenant	Occupier	Rent (£/s)
House	Agnes Hamilton, sick nurse	same	2/2
House	Marion Hood, widow	same	3/5
House	Ann Summers, widow	same	5/15
House	Mary Babes, widow	same	3/0
House	John Ashcroft, labourer	same	2/10
House	Bernard Kerr, carter ¹⁵	same	2/10
House	Euphemia Gilmour, widow	same	2/5
Land	George Warnock, flesher	same	2/10
Land	Andrew Wilson, millwright	same	3/12
Workshop & land		Alexander Calderwood	40/0
House & garden	Thomas Rae, spirit merchant	Anne Rae, Widow	14/0
House	John Calderwood, inspector of poor ¹⁶	same	18/0
House & garden		Alexander Calderwood	21/0
House & garden	John Patrick, clerk	same	25/0

FIXME Alexander Calderwood's 1895 holdings

If the 10:1 ratio between rent and value holds, the houses he owned would be worth in the neighborhood of £1000.¹⁷ At the time of his death, he had also erected a sawmill on his land.

¹⁵ A carter hauled freight.

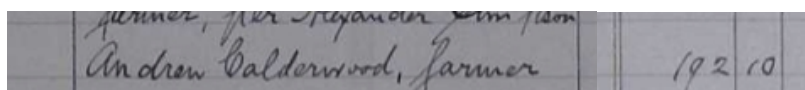
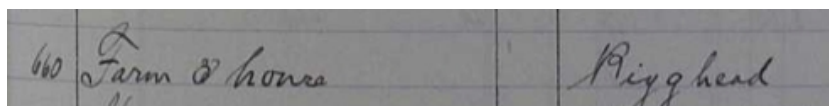
¹⁶ Son of Alexander, I believe, rather than son of John. The Poor Inspector judged if people were eligible for local welfare.

¹⁷ Admittedly, I don't know if there were mortgages.



PHIXME Parkhall St., wide view. Alexander's sawmill building at far right. Undated photo courtesy Bill Niven. (sawmill.jpg)

With his wealth, Alexander became a kind of community banker. His succession inventory lists one hundred twenty-eight individuals and organizations who owed him debts ranging from eight pence to eighty-eight pounds.¹⁸ Among them was Andrew, on the hook for eighteen shillings. Keeping his own brother on the ledger indicates to me that Alexander saw this as a business transaction, not a family favor. About that time, Andrew was paying something like £190 annually to rent Rigghead. Did he have cash flow problems?

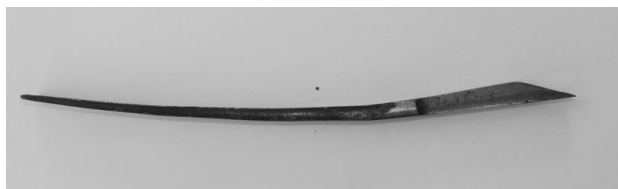


PHIXME 1905 Valuation Roll showing rent for Rigghead. Courtesy National Records of Scotland (VR107/223/259, Crown Copyright) (VR1905_1.jpg, VR1905_2.jpg, VR1905_3.jpg)

When Andrew left East Kilbride in 1908, Alexander had been dead for six years, and his son James held the shop and sawmill. My grandfather, Robert, Andrew's youngest son, would have seen his cousin James prospering while his own family gave up the dairy farm in search of greener pastures in the New World. No wonder he didn't like Scotland.

18 E.g.: the U.P. church minister owed 15s 9p, the parish council, £1 1s, and the local coal company, £4 8s 8p.

Death of a Paper Clip



PHIXME A bent blade in Andrew's tool collection. (bent_blade.jpg)

Tradesmen are notorious for putting their tools to unconventional uses. In my high school carpentry class we were sternly admonished to never use a screwdriver as a chisel. The warning was necessary because, in a pinch, a screwdriver makes a serviceable chisel, though sometimes to the great detriment of the screwdriver. Andrew, in his time, apparently used one of his plane irons as a *lever*, and not a very good one. By overloading the tail end of the blade, he induced what is called *plastic deformation*. Deformation and fracture are important phenomena in metals of all kinds.

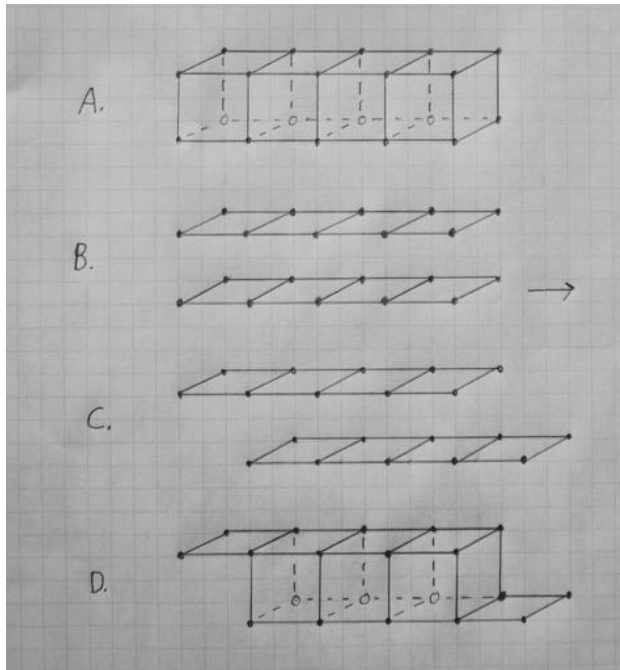
* * *

Unwind a paper clip and then bend it into a right angle. This takes a little work, but the metal will respond. Now bend it back straight and then over in the opposite direction. Still the steel cooperates—remarkable when you think about it. Repeat this cycle enough times, though, and the metal will snap. We have, on the one hand, great flexibility, and on the other, catastrophic failure, both in the same material. What's happening? To see, we must return to the properties of metal lattices.

Let's start with flexibility, looking at a small two-layer cubic lattice.¹ Imagine that the upper sheet of atoms is held at its left end by a clamp, and the lower sheet by a clamp on the right. The lower clamp is then pulled rightward with great force while the upper remains fixed. The metallic bonds give the lattice

1 No actual metals are simple cubic, but we'll start there for simplicity.

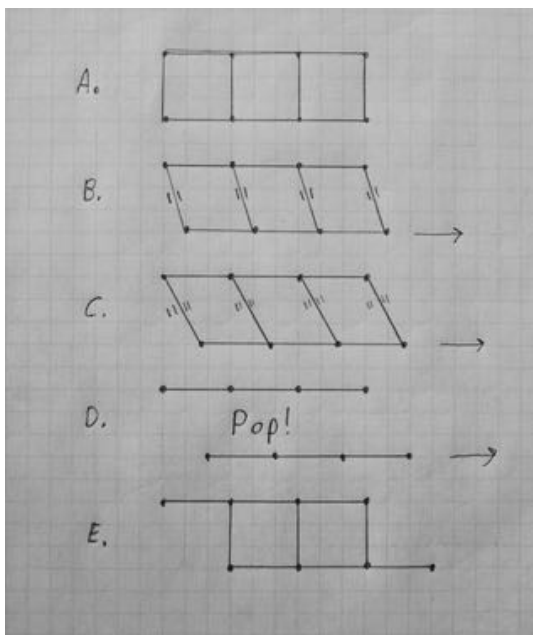
some springiness, and it will elongate a little under the load. But if the force is great enough, the lattice will start to deform as the two layers slide past each other and realign in a new position. In the figure below, we see this progression from A to D (in steps B and C, the vertical bonds between atoms are omitted for clarity).



FIGSME Slipping lattice. Upper layer fixed, lower layer drawn right. (slip1.jpg)

This "slippage" is not fracture—the lattice remains sound but it's been shuffled inside. The changes in the vertical bonds during slip are illustrated with a side view in the next figure. They stretch but eventually fail, and new bonds spring up to replace them. The cubic structure is maintained as the atoms get new partners where old bonds were broken and new ones formed. This is

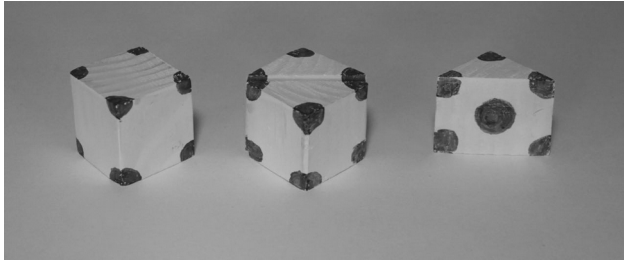
plastic deformation, and the interface between the two sliding layers is known as the *slip plane*. Having slipped once, the lattice can slip again and again.²



FIGSME Side view of an idealized slipping lattice. (slip2.jpg)

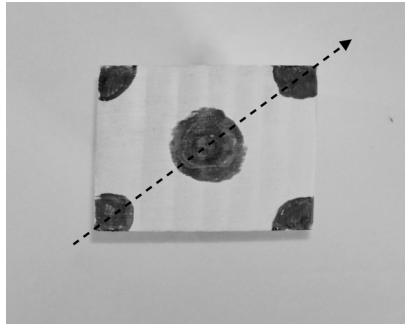
The iron lattice is body-centered-cubic (BCC), so it has an atom in the middle of each cube. This lattice could slip in three rectilinear directions just like the cubic lattice, but it has a better option. To see how, let a wooden block stand for a cube in the lattice. We rotate it slightly and then slice vertically through the diagonal of the top face.

² Since a cube is symmetric in three dimensions, we could stress the lattice up/down or front/back to get the same kind of deformation.



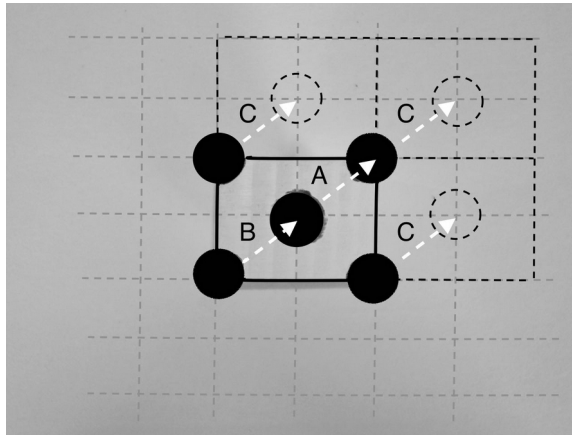
FIGSME Body-centered-cubic: whole, sliced, and front removed. Atoms at the corners are shared with other cubes. They are drawn as partial circles.
(cubes1.jpg)

In the half-cube, imagine an arrow proceeding from the bottom left corner to the top right corner. A lattice of thusly-sliced cubes can slip diagonally in that direction.

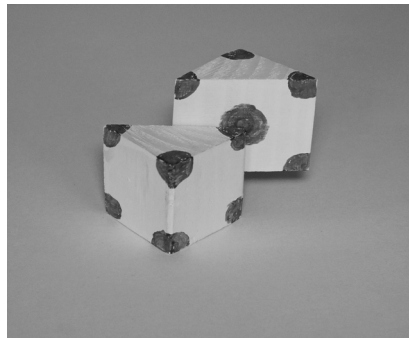


FIGSME Diagonal slip direction (cubesface1.jpg)

As it does, you can see (below) that A, the center atom of the cube, becomes the upper right atom in the same cube, that B, the lower left atom, becomes the new center of the same cube, and C, the three other corner atoms, become new center atoms in adjacent cubes.

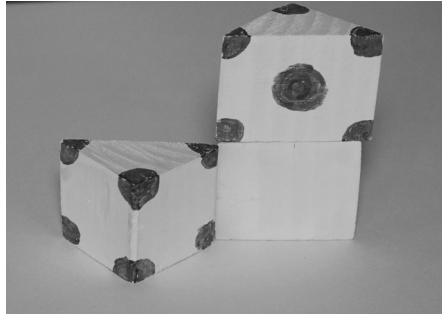


FIGSME Progress of of one cube's atoms during diagonal slip. Atoms in other cubes along the slip plane move likewise. (slipgrid.jpg)



FIGSME Body-centered-cube after slipping one step (cubes2.jpg)

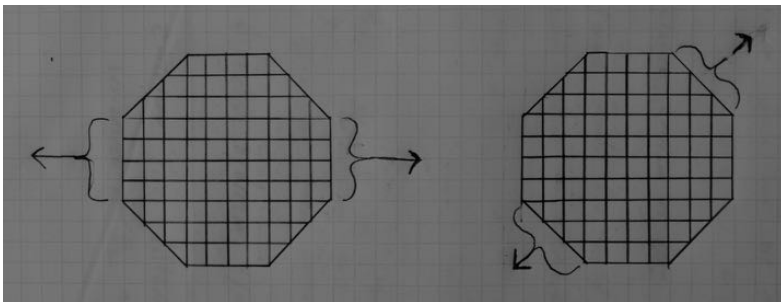
If our cube slips again, the original center atom becomes a center atom once more:



FIGSME After slipping two steps (cubes3.jpg)

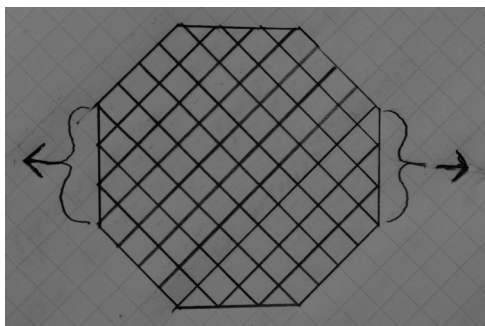
The rule about slipping is that each atom must land in a spot that fits the lattice structure. Though individual atoms move, the overall grid stays the same. The body-centered lattice can slip left/right, front/back, and up/down along the edges of the cubes, but the diagonal slip is favored. Why? Let's say that the sides of the cube are of length 1. To effect a single slip along the sides the atoms must all move a distance of 1. But to move diagonally, the atoms must only go about 0.7. It takes less energy to pull that off, so the diagonal is the *principal* slip plane.

The arrangement of forces that drive one lattice layer left and the other right is called *shear*. Consider the cubic lattice below, with tension applied in two different directions.



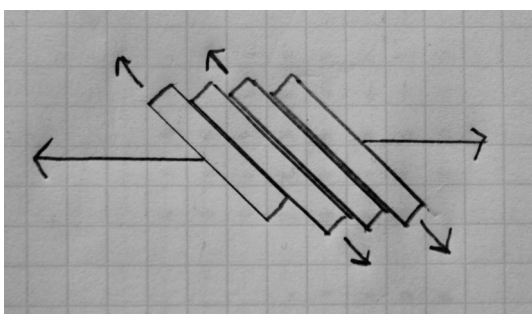
FIGSME Tension applied laterally and diagonally across a cubic grain (tense1.jpg)

On the left, the tensioned layers are subject to the same force in both directions: there is no shear between the layers. But at right the layers are *inclined* to the tension, and Slip Happens. Let's rotate the sample and take a closer look.



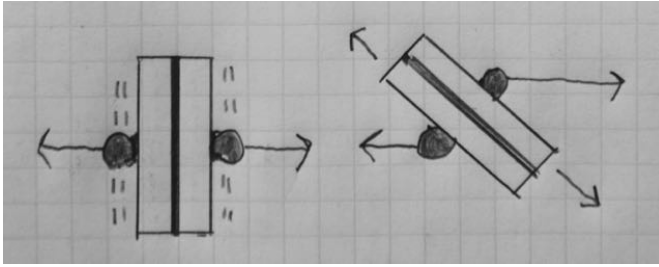
FIGSME Diagonal tension (tense4.jpg)

This situation can be viewed as a stack of diagonal slices. Let's take out a few of them and see their response to tension.



FIGSME Shear from diagonal tension (multislip.jpg)

You can think of the stack as some very strong refrigerator magnets placed back-to-back. If the magnets are oriented vertically, like coins in a roll, it's hard to separate them by pulling from the ends. But if the magnets are at an angle you can make them slip apart.

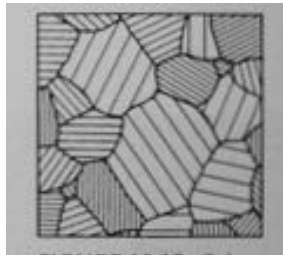


FIGSME Separating two magnets. Left: the hard way, right: easier. (magnets.jpg)



FIGSME Deformation of a monolithic zinc lattice under tension (REPLACE [MSE])

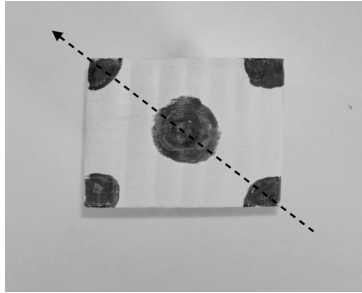
Above, the deformation of a large, nearly perfect lattice is illustrated, showing well-ordered slip planes. The zinc sample was created under special conditions to produce a single crystal. Steel, however, is made of innumerable grains, each having its own lattice orientation. The grains make a kind of crazy quilt, as shown below.



FIGSME Lattice orientation in grains (REPLACE [MSE BOOK])

As tension is applied, grains at various orientations will undergo slip, and the metal stretches. At first blush, this may seem impossible: after all, the principal planes in the patchwork don't line up. But I have not yet fully elaborated.

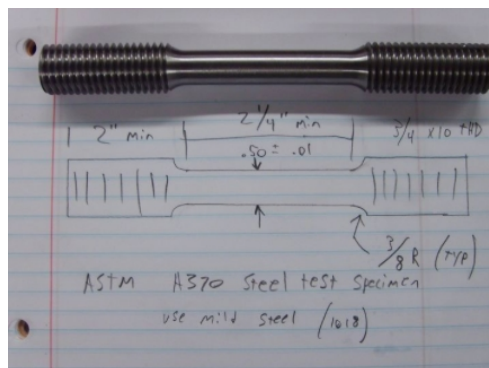
In the wooden block, we saw the principal, diagonal slip plane of the body-centered-cubic lattice, going lower left to upper right. But it could just as easily slip along the other diagonal, *lower right to upper left*.



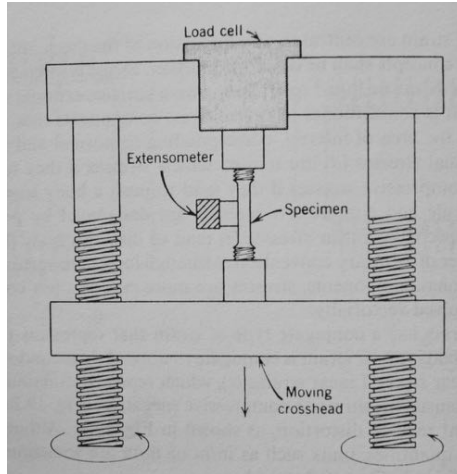
FIGSME Alternate diagonal slip (cubesface2.jpg)

The cube can be sliced diagonally in six principal planes, each slice affording two slip paths with each path mobile both forward and backward, giving every grain a smorgasbord of slip options. Moment by moment, the planes respond to the three-dimensional forces acting on them. Like an analog computer, they "solve" the physics problem of which of them is best able to move. Deformation across the grain boundaries happens through *multiple slip*, where grains deform on more than one plane at a time, accommodating the mismatched lattices that join them.

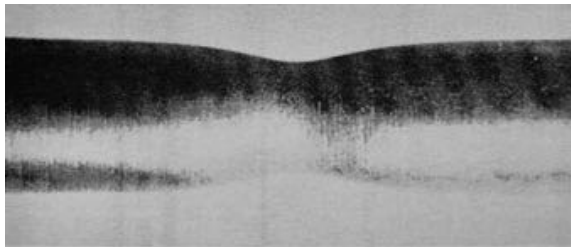
At some point, however, the metal snaps. The ability of steel to resist fracture in tension is called its *tensile strength*, commonly measured with a Tensile Test Machine. The machine accepts a rod of sample material, and applies enough force to break it.



FIGSME Tensile test specimen. Threads attach the sample to the test machine.
(REPLACE)



FIGSME Tensile test machine (REPLACE [MSE BOOK])



FIGSME Necking under deformation (REPLACE [MSE BOOK])

As the test piece stretches, it shrinks in diameter. This phenomenon is called *necking*.³ If a piece of steel is stressed like this, it is damaged beyond repair.

3 Necking takes place in multi-grain samples. The single-grain zinc pictured earlier did not neck.

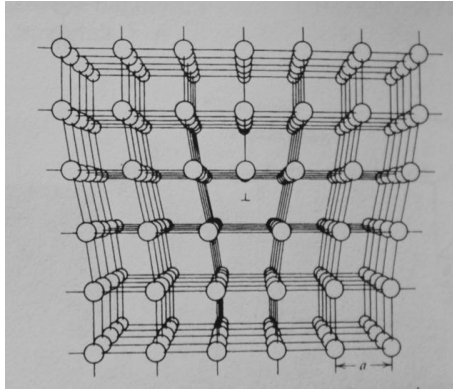
Mechanical and civil engineers will allow enough safety margin in their designs so that steel members are not pushed to this point. But if steel is accidentally loaded beyond its *yield* strength (where it begins to deform), it undergoes considerable plastic deformation before it actually fails. This is a good thing.⁴

* * *

The Slip Story I have presented so far has a serious flaw. The atomic bonds across the slip plane do *not* break and recover in unison. That would require tremendous force—far more than what is needed to effect slip in real life. The ideal lattices shown so far in this book do not exist in steel, even within a single grain. It is, in fact, possible to grow a perfect lattice from a starting seed. Single-crystal "whiskers" of pure iron can be made and have fantastic strength. But even allowing for the misaligned grains in steel, the product we get from the mill isn't nearly as strong as theory would predict. Metallurgists found the explanation in *defects*: disruptions of the lattice. A variety of defects weaken a lattice and make slip possible.

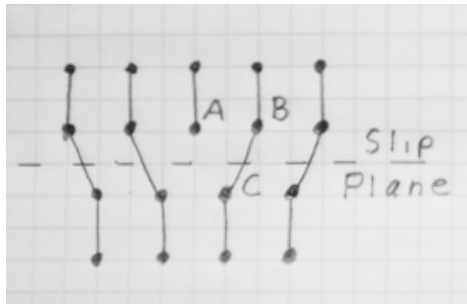
Point defects are the simplest: problems at a single atomic location that upset the desired order. An example is where an iron atom is simply missing. The lattice then has a *vacancy*, with a consequent loss of strength. At other times, a carbon atom takes the place of an iron atom—a *substitution*—again compromising the lattice. There can also be contaminant atoms (like phosphorus) that either wedge into the lattice like carbon or replace iron atoms. But while point defects weaken the lattice in various ways, they do not disturb its basic geometry. That ignominy falls to *dislocations*.

4 Glass is actually a strong material, too, but it shatters when overloaded.



FIGSME Edge dislocation diagram (REPLACE [MSE BOOK])

Above is the classic presentation of an *edge* dislocation.⁵ The vertical half-plane in the middle creates a zone of distortion where the lattice can't maintain uniform atomic spacing. Let's zoom in:

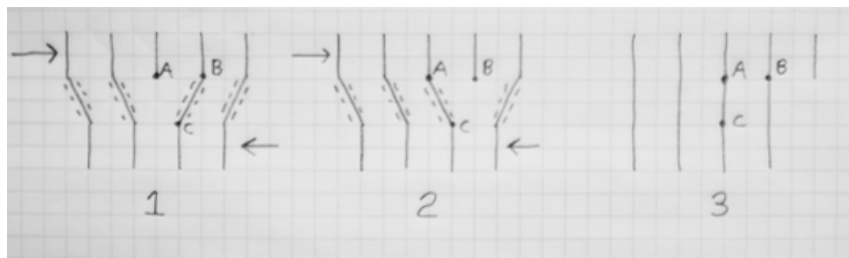


FIGSME Key atoms in an edge dislocation (edge2.png)

Call the atom at the lower tip of the half-plane A, the atom to its right B, and the atom below them both C. Atoms B and C are bound across the slip plane, while A is unbound. In the figure below, we apply shear forces, so that the top of the crystal is driven right, while the bottom is driven left. The bonds that stretch across the shear plane come under stress. But of all the atoms, only C has the opportunity to freely re-pair with another atom. The B-C bond breaks,

⁵ So named because the dislocation will extend all the way to the edge of the lattice. The *screw* dislocation is rather harder to visualize on paper, and I will omit it.

A-C forms, and the half-plane of dislocation "moves" to the right. After another cycle, the half-plane has emerged on the right side, and the top half of the crystal has shifted by one half of a lattice space. Motion thus happens as dislocations go ka-chunk, ka-chunk, ka-chunk down the slip plane, breaking a single atomic bond at a time.



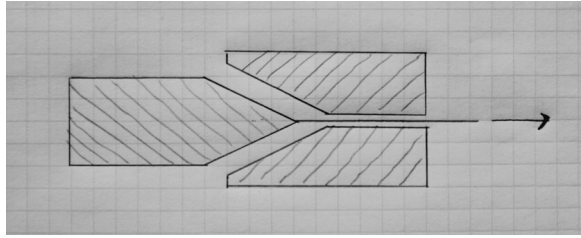
FIGSME Three stages of edge dislocation movement under shear (edge_move.png). The top half of the crystal is slipping right.

While shear arises from opposing tensions, it also takes place under compression, as when metal is pounded. As a blacksmith hammers a piece of iron he induces plane slips that reshape the metal. The process is an example of *hot-working*. The "working" process moves existing dislocations and creates new ones along the way. In the heat of the forge the iron can relax a bit, letting some of the dislocations heal and so relieve internal stress in the lattice that might cause it to fail under the his blows.⁶

When an unheated steel ingot is passed through powerful rollers to make a flat product, it is *cold-worked*. The wire of our paper clip was also cold-worked in a process called *drawing*. A steel rod having a whisker at the tip was fitted to a conical die having a hole at its apex. The rod was turned into wire by pulling it whisker-first through the die under great tension.⁷

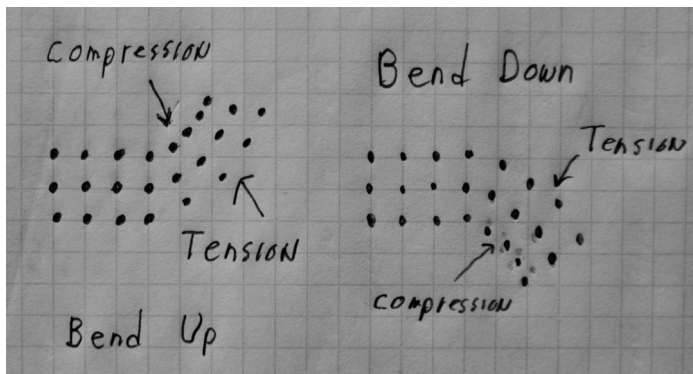
6 And while the iron is hot, the lattice will be more willing to deform to begin with.

7 Pushing metal through a die (from behind) is called *extrusion*.



FIGSME Steel rod with whisker, and the die through which it is drawn (draw.jpg)

When we bend our paper clip back and forth we are cold-working it, forcing plane slips by both tension and compression. This can be seen in a simplified three-layer lattice:



FIGSME Alternate tension and compression. At left, top layer in compression, bottom layer in tension. At right, top in tension, bottom in compression. The middle layer is neutral in both (tense_compress.jpg)

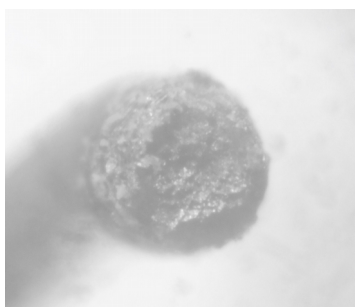
Dislocations create weaknesses that help us deform the lattice. But in all the slipping, dislocations tend to pile up—they run into each other and can't get past. Where the dislocations jam, plane slips become more difficult. The metal, refusing to deform further at those points, becomes harder. The phenomenon is known as *work-hardening*. As hardening progresses, the wire becomes less and less compliant. Fewer slip paths remain, concentrating additional slip into smaller regions.

All the slipping and sliding will eventually produce a macroscopic *crack*. Tiny cracks may pre-exist from the manufacturing process, but motion of the

crystal planes opens up *microvoids*. Weak spots also exist around inclusions and contaminant molecules that bond only slightly or not at all with the lattice. Under stress, tiny gaps appear between these intruders and the iron atoms. And if the boundaries between grains are brittle, openings will appear there as well. During plastic deformation, all these kinds of voids have the opportunity to coalesce and grow. Eventually, the structure becomes so compromised that it fractures.

To break a length of paper clip wire by pulling on the ends is beyond the ability of a human, even with hand tools. But mere flexions induced by our fingers are enough to bring its demise.

Pity the paper clip...



PHIXME Fractured paper clip wire (broken.jpg)

"Harmless Lunatics"¹

Steel has more sinister applications than woodworking, and Andrew wielded it in the form of an instrument for war. In 1859, Europe in general, and England in particular, regarded Louis Napoleon Bonaparte (Napoleon III) with increasing alarm. British national confidence had been shaken by the 1857 rebellion in India. Now the country's long-standing anxiety about France was further heightened because Louis had just survived an assassination attempt, the plot for which was hatched *in* Britain. Though an Italian was the ringleader, this event provoked great anti-British fervor in France, and the United Kingdom had cause for worry.

Against this backdrop the Queen's armed forces were stretched thin by the demands of the Empire. It was not clear that the navy could prevent the French from crossing the Channel, nor that the army could repel them if they landed. During the recent Crimean War, the English army was plagued by command mistakes (such as the Light Brigade affair), and these gaffes eventually brought down the government in London. As the specter of the third Napoleon grew, alarm over British preparedness crested into a panic among the populace, and a clamor arose for bolstering the nation's military. Britain had a professional army of paid volunteers and the power to create militia forces by conscription. While government officials also harbored concerns about France, they faced a dilemma: at the time, it was considered politically impossible to either spend more money on the regular army or to reinstate conscription. The former would mean higher taxes while the latter would disrupt the labor force. What to do?

During the turn-of-the-century wars of Louis' uncle, Napoleon I, a third armed force had existed. The "Volunteers of 1803" were community-organized groups carrying their own weapons. Their nominal purpose was to harass any invading force with guerrilla tactics. They had little training and were not part of the army. The volunteers never saw combat and they disbanded after the French naval defeat at Trafalgar. But their memory survived and in the

1 Owen Wethered, a Volunteer Force officer, speculating on the regular army's opinion of the volunteers.

excitement of 1859 men began forming volunteer corps once again and offering their services to the crown. As in 1803, the government was unsettled by the prospect of armed, semi-organized, ill-regulated men loose in the nation. Various political and military leaders did their best, in public and private, to prevent the re-emergence of this force, but the popular movement was irresistible. The government finally embraced the volunteers under the contradiction that they were self-sufficient, hence costing the state no money, and yet were somehow under London's control. These premises would lead to endless tensions as the realities of volunteer independence and subordination played out over the years, but the public's demand for action was satisfied.

Assuming that a locally operating volunteer corps could feed and house itself, its remaining requirements were for weapons, ammunition, uniforms, and, most of all, training, and the government would become involved with each. Slowly, the corps were issued standard military rifles. Ammunition was provided at cost. Each corps designed and provided its own uniforms, some quite fanciful (the government eventually forced modesty and standardization). But the real challenge was training and its concomitant, discipline. Each corps was free to establish its own rules, provided they were approved by the government, but a universal feature of the volunteer force was that any man could, in peacetime, quit on two weeks notice. Members of the army and militia were subject to harsh punishments for disobedience or errors. But given that the volunteers were not paid and could walk out practically at will, it was understood that they could not reasonably be subjected to military law, though attempts were made from time to time. Order was maintained only by good relations between officers and men.

The original model for volunteer demographics was that middle class men would form the rank and file. These men would have the economic means to supply themselves with uniforms, etc., and would hopefully be fairly intelligent. Upper class gentlemen would become the commissioned officers, aided in their authority by high social standing. The volunteer force was not intended for the lower classes—their proper role in national defense was held to be in the army or the militia. The original composition of the volunteers fit this model fairly well, but as time wore on more participants came from farther down the economic ladder. They could not afford to equip themselves, which put pressure on the richer officers to make up the difference. Eventually, the

government was forced to pay some of the volunteers' expenses, but in exchange, London demanded more control of the force. Parliamentary wrangling over money for the volunteers would go on for much of the program's fifty-year existence and presented the hazard of volunteers, some of them M.P.s, directly inserting themselves into domestic politics.

While there were four different kinds of volunteer companies (rifle, artillery, mounted, and engineer), rifle companies far outnumbered the others. These companies were trained in infantry maneuvers and musketry. The degree to which such drill was generally successful might be inferred from an 1881 satire entitled, *How Not To Do It: A Manual for the Awkward Squad*:

In the "Manual exercise with the Short Rifle" there are a variety of movements which deserve the recruit's serious attention; we will, therefore, omit them here and touch only one point which merits no attention whatever. "Secure arms" is an order which is accomplished in the following way:—the rifle being at the right side of the body, in the right hand, with the muzzle pointing upwards and the stock (curiously enough) straight down—is seized by both hands and transferred suddenly to the left side of the body, the stock being thrown with a jerk under the left arm. Now, in performing this feat, be as careless as possible, because the slightest degree of carelessness will cause you to send the butt of your piece into the stomach of the man on your left, which, if done effectively, will floor him. The value of this movement on review-day is immense, for, supposing that each man floors his comrade, only the right files of the whole regiment will be left standing, and to the spectators it will appear as if the enemy made a successful and awful attack, while the men struggling on the ground will have a terribly real effect.

The officers do not come off much better in this mock battle:

"You see those fellows?"

"Yes"

"That is Colonel Slog's battalion. He has been ordered to support Ringwood, whose men occupy the scrub, but with his usual clearness of perception, Slog has mistaken him for the enemy, and, as you see, is attacking them. Ringwood, with his wonted hot temper, is evidently bent on giving him a warm reception, though he understands the mistake well enough."

The general population often regarded the volunteers as clowns and treated them accordingly. The book *Trifles or Little Things for Volunteers to Think About* entreated volunteers to conduct themselves with proper discipline and deportment at all times, advising:

Do not trouble yourself about sneering remarks from ignorant people, and do not argue where argument can evidently do no good. If people make insulting allusions, it is best to treat them with silence. Keep your temper and show them your superiority...

But while the volunteers may have been incompetent on their feet, they had the opportunity to become good marksmen. Each rifle company was required to have access to a large field for gunnery practice. Without telescopic sights, they had to shoot at targets hundreds of yards distant. To encourage proficiency, the government eventually established a system of small bonuses for good shooting, and individual companies held annual competitions for prizes donated by good-hearted citizens. For many years, my branch of the Calderwood family has possessed such a prize: a silver goblet with inscrutable lettering:

I Company, Second LRV, presented by J.C. Craddock, esq,

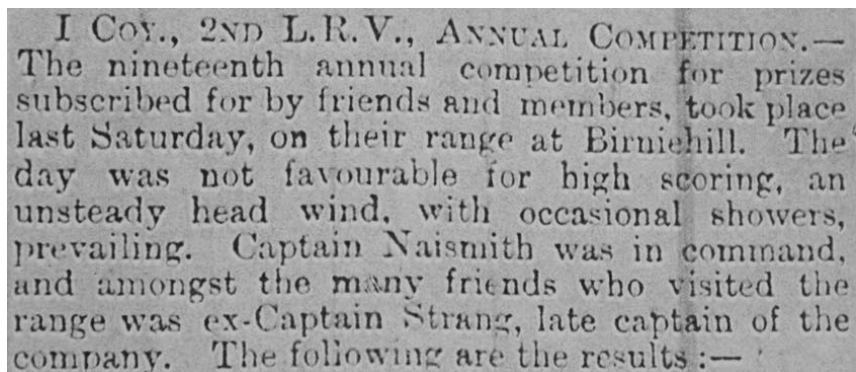
Won by Col.-Sergt. A. Calderwood 1886



PHIXME 1886 prize cup (cupA.jpg)

LRV stood for *Lanarkshire Rifle Volunteers*, Lanarkshire being another name for the county containing East Kilbride. Lanarkshire raised more volunteer corps than any other county in Britain, and Scotland generally embraced the volunteer movement with greater enthusiasm than England, with roughly twice as many men joining, per capita. *Col.-Sergt.* stands for Colour Sergeant. A

Colour Sergeant in the "real" army was one rank above an ordinary sergeant, and his nominal duty was to protect the junior officer who carried the regimental colors in battle.



I COY., 2ND L.R.V., ANNUAL COMPETITION.—
The nineteenth annual competition for prizes
subscribed for by friends and members, took place
last Saturday, on their range at Birniehill. The
day was not favourable for high scoring, an
unsteady head wind, with occasional showers,
prevailing. Captain Naismith was in command,
and amongst the many friends who visited the
range was ex-Captain Strang, late captain of the
company. The following are the results :—

PHIXME Description of match where Andrew won the cup. From the Oct. 2, 1886
Hamilton Advertiser, courtesy East Kilbride library (hamilton.jpg)

Official records of the volunteers are notoriously scarce, and there is the added complication that some volunteer companies were disbanded, renumbered, or reorganized. In an 1877 shooting contest, Andrew won a pistol that is inscribed with "16th LRV," while the 1886 cup is marked "2nd LRV Company I." Close inspection of Rifle Volunteer literature indicated that the 16th was originally formed in 1860, but then enlarged in 1873, absorbing several other corps. Then in 1880, the 16th was renumbered as the 2nd (the original 2nd having been absorbed elsewhere long before).

Andrew was almost certainly a member of the 103rd LRV of East Kilbride. That unit was merged into the 16th LRV in 1873, and later became the 2nd. I tried to track him down in the maze of the archival bureaucracy. Searching the online index at the British National Archives, I found two records (I shall call them X and Y) that might shed light on these Lanarkshire volunteers. Each was in the category of "Muster Rolls and Pay Lists" from War Office File Series #13. X covered all Lanarkshire volunteers from 1873-1878; Y only the 2nd LRV, from '72-'76. From the index, I could not tell how many pages were in either document, how many pages were relevant to my needs, or even what information they held. Given these uncertainties, I was not going to make a personal trip to inspect them.

The archives offered a paid research service that cost £20 for every fifteen minutes of work.² I sent the Research Service an inquiry about searching *Y* for information about Andrew. Because *Y* ended in 1876, it was not an ideal choice: 1877 was the earliest we knew for certain that Andrew was a volunteer. However, *Y* was presumably much shorter than *X* and would not cost so much to investigate.

But the Research Service responded that it might be quite expensive to do this work and suggested that I contact the Copying Service and obtain a copy of the entire document. This could probably be done quicker and cheaper than a paid search. I duly sent a copy request to the Copying Service for the whole of *Y*, and was quoted a price in excess of £700! Startled, I tried asking for copies of only those pages of *Y* relevant to Andrew's company in the 2nd LRV. The Copying Service replied that this request was too complex for them, and suggested that I arrange for a researcher to come examine the materials and copy only the pages I wanted.

So I contacted the Research Service again, asking for them to find and copy the pages about Andrew's LRV company. This would presumably be much easier than a search for Andrew, himself. They replied that making copies was the job of the Copying Service and that I should talk to *them* instead. I replied that the Copying Service had already declined to do that job and wasn't there *someone* who would be willing to help me?

I finally got a message telling me about a standard service for searching Muster Rolls and Pay Lists. For a flat fee of £38, they would search a single volume for any one individual, and would provide me a standard information packet of results. This meant I could have the much larger *X* searched at reasonable cost, a search that should be guaranteed to turn up Andrew. However, I would not get to specify the data to be collected, nor see the whole record for his LRV company, a record that might yield very interesting information about Andrew's companions.

I had them start the search, but in a moment of inspiration I asked that the researcher make note of the *pages* where any information was found. That way, I could turn around and give those page numbers to the Copying Service to retrieve the whole pages. If those copies indicated that there was useful

2 One pound was approximately \$1.50 at that time.

information located nearby, I could hunt it down with targeted copy requests, shaking the bushes until the data fell out.

Sadly, the search came up empty. The document was a Pay List for officers with salaries, containing no entries of incentives paid for shooting proficiency. Searches of other War Office documents also failed, so I was not able to learn much about Andrew's paramilitary career. But I found a consolation prize at the National Library of Scotland: rules for the 103rd corps of East Kilbride.



FIGSME 1868 rules of 103rd LRV (FIXME PERMISSION) (rules.jpg)

The rules themselves are not terribly interesting, but scribbled on the backside of the page is a nearly illegible note:

Dear Harrington: I send you a copy of the rules as approved by Her Majesty for your Corps. Your ammunition has come, and the targets are also ready, but I hear there is some hitch with the banner[?] about the ground. This is a pity as it is a great thing to get the shooters with a team this great.

* * *

In 1886, Andrew would have been shooting with a Martini-Henry rifle having a steel barrel.³ The original armament of the Volunteers was the Enfield rifle, a muzzle-loader with an iron barrel that England also sold to the Union and Confederate armies in America (the smart arms merchant always sells to both sides). In the mid-1860s, France developed a breech-loading rifle, the Chassepot, and the British army quickly realized the importance of adopting

³ In Joseph Conrad's *Heart of Darkness* (1899), there is a Martini-Henry rifle in the wheelhouse of Marlow's steamer as it proceeds up the Congo River.

this technology.⁴ As an interim step they began altering Enfield rifles by adding the breech mechanism of Jacob Snider, the result being known as the Snider-Enfield. For the long term, the government announced a competition for arms makers to design a completely new weapon. When none of the entrants proposed a satisfactory rifle, the army decided on a hybrid from two contenders: the breech by Friedrich Martini and the barrel by Alexander Henry. The rifle was just over four feet long, weighing eight and one-half pounds, sans bayonet.



FIGSME Martini-Henry rifle (REPLACE? [wikipedia] martini.png)

In 1886, a Mr. R. McVittie published a booklet for the Volunteers, titled *Hints and Advice on Rifle-Shooting*, which begins:

Target-shooting has been pronounced the most manly of all outdoor exercises, and it is a very laudable ambition on the part of any man to aspire to proficiency in the art.

Of the Martini-Henry rifle, he says it is effective up to 600 yards, but that the accuracy varies with the manufacturer. He also notes that the rifling in the barrel wears out quickly, and recommends that a new barrel be fitted every year, a luxury I suspect the Volunteer force did not enjoy. The Henry barrel had a seven-sided polygonal bore. The force generated by the bullet squeezing through the deep channels presumably caused the high rate of wear.

4 While a muzzle-loader has its powder and "ball" stuffed down the barrel from the front, a breech-loader accepts cartridges through an opening at the rear of the barrel—a much faster operation.



FIGSME Martini
Henry bore
(heptagon.png)

His treatise goes on to give advice on shooting positions, adjustment of sights for wind, light, and humidity, and further warns of poor quality control in the manufacture of cartridges. He says the breech and barrel are subject to a buildup of gunpowder residue in hot or dry weather, and may need frequent cleaning during a shooting match. How a soldier in combat would deal with this problem, he does not discuss.

In the 1877 competition, Andrew may have been wielding the Snider-Enfield. The breech-converted weapons kept the iron barrel, but rifles built new as Snider-Enfields had steel barrels. While the steel barrel was supposed to be longer-lasting than the softer iron, there were apparently manufacturing problems. An anonymous 1876 publication, *The Rifle Shot's Manual*, states:

There was, until very recently, a considerable difference of opinion as to the respective merits of steel and iron barrels; but while it is possible that a good barrel of either material cannot be affected or prejudiced by the particular metal of which it is composed, practical experience has shown that steel barrels are not so reliable as those made of the softer metal, i.e. they do not perform so uniformly well and you cannot depend upon getting a perfect barrel made of steel so certainly as you can if you order one made of iron; and, as a matter of fact, many of the best shots have returned to iron barrels after a trial of the new steel barrels.

The reason for this is that the manufacture of steel barrels is so much more difficult that it is not easy to turn them out perfect, or, if perfect when turned out, they are liable to "chip" in use...⁵

The author goes on to say that the "stouter barrels" of small-bore rifles (like the Martini-Henry), had much less trouble with steel in this respect. If those thicker barrels came out better, it may be that the thin barrels had their shape

⁵ The very end of the rifle bore is called the crown. If chips come out of the crown, the rifle's accuracy will suffer.

distorted by the heat of drilling out the bore. A thick barrel would be less subject to warping during that process.

The Volunteer force was finally disbanded in 1909. The men never saw action at home, but some wound up as participants in the Boer War. Personally, I think the government took the wrong approach with the Volunteers. Rather than preparing them for combat, for which they were ill-suited, it should have simply trained them to surrender, en masse, and swamp the enemy encampments with their numbers—a scheme worthy of Monty Python, and it might have worked: *Monsieur, nous avons capturé un autre cinquante Volontaires de Fusil. Ils veulent que le déjeuner.* (Sir, we have captured another fifty Rifle Volunteers. They want lunch.)



PHIXME Pistol won by Andrew in 1877 (pistol.jpg)

Rust Never Sleeps

Ask any historian: the number one dead-end for his research is fire. After combustion, the next major bugaboo is water. Fire and flooding have probably erased as much history as all the deliberate ravages of war. When my parents moved to a condominium complex, they were given storage space in the basement. My father kept Andrew's tools down there, and he wisely put the box up on a pallet to raise it above floor level. Unfortunately, water came in through the ceiling. As noted in *The Next Whole Earth Catalog*, "Tool steel rusts horribly." The damage to the Scottish artifacts was not extensive, but a number of the blades acquired an undesirable new patina. Rust is an example of the more general process of *corrosion*, by which useful metal objects are gradually turned into junk.

* * *

In the Heavy Metal chapter, we were introduced to atoms and their cloud-decks of electrons. We learned that atoms like to have complete overcast in their cloud decks, and they achieve this in molecules by sharing electrons with other atoms. This union of electrons 'twixt two atoms is known as a *covalent bond*.¹ However, other kinds of bonds exist. The iron lattice is made of *metallic bonds*. In a metallic bond the outer electrons are still shared, but shared so loosely that they can wander all over the lattice rather than staying close to individual pairs of bound atoms. The freedom of these electrons is what makes metals good conductors of electricity.

In the story of corrosion, ions (EYE-ons) are important and their properties are apparent in an *ionic bond*. Like the north and south poles of magnets, positively and negatively charged atoms are naturally attracted. Electrical charge in an atom is split between the positive protons in the nucleus and the negative electrons whirling around it. An atom normally has equal numbers of protons and electrons so that the whole package is neutral. But some atoms have a very weak hold on an outer electron or two, and sodium is a case in

1 The electrons that get shared are known as *valence* electrons, hence the origin of the term "covalent."

point. When sodium and chlorine meet to form ordinary salt (NaCl), the chlorine atom, rather than *sharing* sodium's outer electron, captures it outright and so fills its own outer shell. The sodium atom, down one electron, becomes positively charged while chlorine, having gained one, becomes negative. These opposites attract and link in an ionic bond, forming a neutral molecule.

Atoms that voraciously acquire electrons are highly *electronegative*; those that gladly surrender them, highly *electropositive*. Each chemical element falls in a range between the positive and negative extremes. Which of two atoms can acquire the other's electron depends upon which is the more electronegative in comparison to the other (a given atom might be a donor in one case and a recipient in another). The greater the difference in negativity, the more likely is an actual capture.

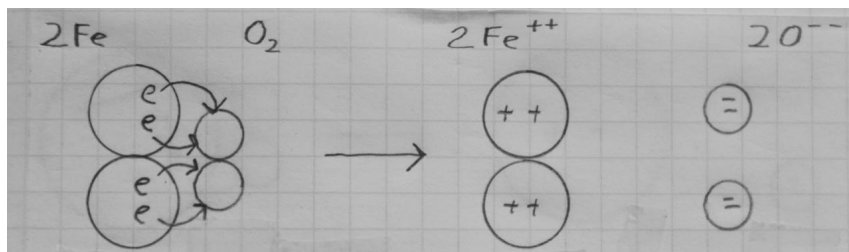
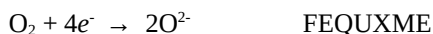
Electron clouds form a kind of shield around the nucleus, hiding the positive charge within. In metals, the shielding provided by the inner electron shells is so effective that the outermost electrons don't much "feel" the attraction of the protons. That's why those electrons are so footloose. The shielding concept applies to molecules as well. In O₂, a comparatively small number of electrons are stretched thin covering the protons of the two nuclei. Other electrons that come near an oxygen molecule can feel the positive pull of the protons and jump in, as we'll see shortly.

Chemists have long known that oxygen combines with a great many other elements. When magnesium (Mg) bonds with oxygen in MgO, the magnesium is said to be *oxidized*. Oxygen's affinity for attaching to other atoms is partly due to its great electronegativity, exceeded only by that of fluorine. Since oxygen is so prevalent on Earth, metals, being electropositive, are almost always found in union with oxygen as oxide compounds. The function of the medieval bloomery was to rip oxygen off of the iron atoms, and a modern steel furnace does the same. Iron ore decontaminated of its oxygen is said to be *reduced*, a term coined before the actual chemistry was understood.²

The great affinity of oxygen for metals does not end after the metal leaves the refinery, and corrosion is the process by which metal and oxygen reunite. For starters, consider a reaction called *dry corrosion*. Take a freshly-made iron rod

2 When reduced, an atom (or molecule) *gains* electrons. When stripped from iron, oxygen surrenders electrons to its former partner.

and stick one end in the sand in a location with persistent low humidity—*really* low humidity. The exposed iron surface will come into contact with atmospheric oxygen. As an O_2 molecule in the air touches the electropositive iron surface, it snatches four electrons and splits into two oxygen ions:³

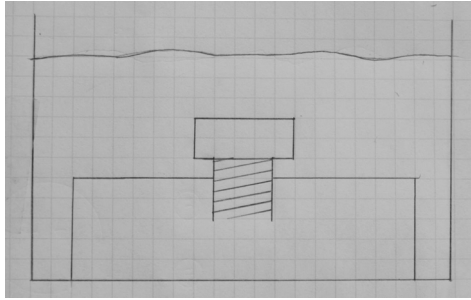


FIGSME One oxygen molecule taking two electrons from each of two iron atoms
(surface_O2.jpg)

The iron atoms in question become positively charged and the negative oxygen ions bond with them. In time, a layer of iron oxide develops on the surface. As it thickens, the process slows, for oxygen must diffuse deeper and deeper into the lattice to find vulnerable electrons and it has trouble getting in. The reaction is called *self-limiting*. In a natural environment, only a minimal layer will form, but it offers some protection against subsequent corrosion. The process is called "passivization."

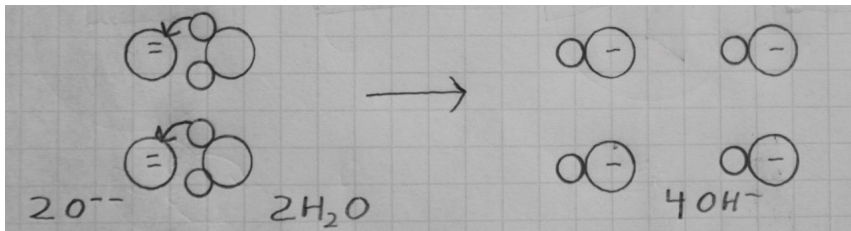
To get rust, we must bring water into the process, and I will do so via *crevice corrosion*. Imagine an iron block with an embedded iron bolt, submerged in a water bath. Further imagine that the bolt is a little loose, so there's a small opening under the bolt head.

3 e^- is an electron, and the superscripts $-$ and $2-$ signify one or two negative charges on an ion.



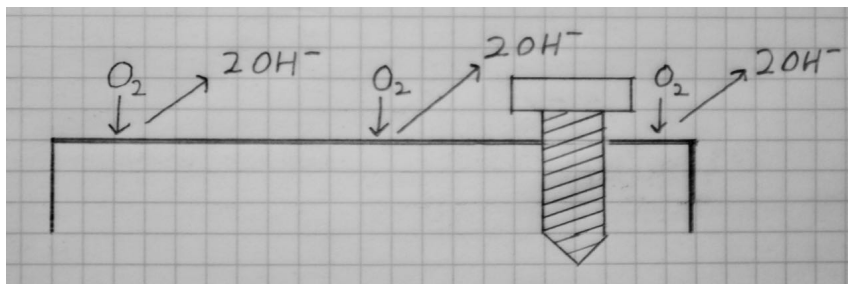
FIGSME Loose bolt in a water bath (embedded.jpg)

The water will ordinarily contain some dissolved air, meaning that O_2 is present in the liquid. As oxygen molecules touch the iron, electron transfer will begin. In the case of dry corrosion, the newly-created O^{2-} ions would bond with iron in the lattice, but in the bath they cannot. We have seen that water molecules are polar: they have an imbalanced distribution of electric charge. The new O^{2-} ions, negatively charged, are quickly drawn to the positive points on H_2O (the hydrogen atoms). Each ion snatches away one hydrogen, thus:



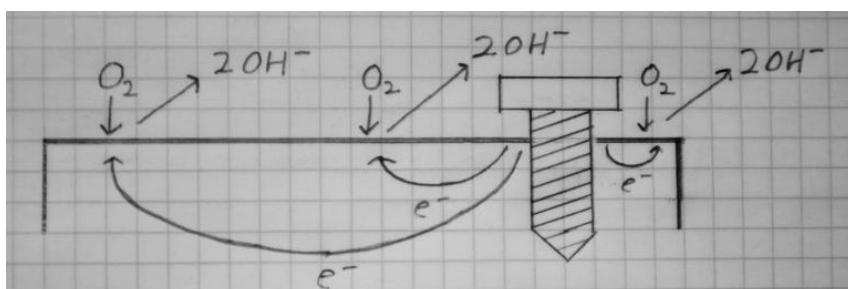
FIGSME Two O^{2-} ions each taking one hydrogen atom from one water molecule ($O^{2-} + H_2O$.jpg)

The oxygen ions, now wedded to hydrogens in *hydroxyl* groups (OH^-), are unable to join the iron.



FIGSME Corrosion reaction on exposed surface (oxycell1.jpg)

With oxygens capturing electrons all over the surface, the metal will become positively charged, or so one would think. But consider the crevice: it's a confined space with a lot of metal relative to a little water. Elsewhere on the block, dissolved oxygen consumed near the lattice can be quickly replaced by other oxygen in the bath. But within the crevice this is not so. The oxygen there gets used up and electron capture slows or even stops. The crevice develops a surplus of electrons relative to the exposed metal that's still losing them. A voltage difference develops, and charge is pulled out of the electron-rich crevice towards the electron-deficient surface in an electric current. The electrons in the current replace those taken by the oxygen, keeping the exposed area electrically neutral.



FIGSME Electron replacement (oxycell3.jpg)

And the metal inside the crevice? The electrons most loosely attached to the iron atoms—the ones to become the current—are the two outer valence

electrons. As the valence electrons depart, the Fe atoms lose their ability to bond with the lattice. They come loose and take their now-positive charge with them, becoming Fe^{2+} ions in the water. This flow of positive charge into the crevice matches the loss of negative charge on the exposed surface. The water bath accumulates positive and negative ions (iron and hydroxyl), and when they find each other they form neutral $\text{Fe}(\text{OH})_2$.⁴ The reaction is a complete electrical circuit, and the metal under the bolt head gradually dissolves away.

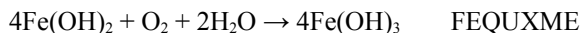
This process falls under the category of *electrochemistry*: reactions that are driven by the movement, rather than re-arrangement, of electrons. The source of electrons is called the *anode* and the destination is the *cathode*. In a corrosion reaction, the anode disintegrates as its electrons depart.

When the early chemists studied oxidation, they did not know that oxygen was grabbing electrons, but that's the key phenomenon of those reactions. Nowadays, any atom that captures electrons is said to be oxidized, even if no oxygen is involved. Oxidation and reduction always occur in tandem, and they're known as *redox* reactions.

But we don't need a crevice for corrosion. The most common form of this malady is *uniform corrosion*, where the entire surface is compromised. Though the process is called uniform, it happens because the metal surface is far from uniform. At the atomic level, even a well-polished surface is irregular, with microscopic hollows, mountains, and cliffs. There will always be places more accessible than others to the dissolved oxygen. This greater access may be purely temporary as both the vulnerable atoms and the oxygen supply are locally consumed, but so long as it lasts, small anodes and cathodes can develop close together with electron transfer in between. The lattice exterior becomes an ever-shifting battleground of localized corrosion that spreads throughout.

But this corrosion is not yet rust. From iron oxide our metal came, and to iron oxide it must go. Water near the corroding metal is filling with $\text{Fe}(\text{OH})_2$. This molecule reacts with O_2 and H_2O , gaining another hydroxyl to become $\text{Fe}(\text{OH})_3$:

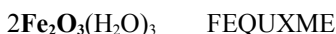
4 Though the iron ions are released in the confined space of the crevice, electric attraction serves to pull them towards the hydroxyls. The dissolved neutral O_2 molecules are unaffected, so the crevice remains depleted of oxygen.



$4\text{Fe}(\text{OH})_3$ has four atoms of iron and twelve each of oxygen and hydrogen. The formula⁵ can be re-written as:



or



Fe_2O_3 is our old friend red iron oxide—iron ore—now embodied in rust. Each oxide molecule has been "hydrated" (combined with water) three times. If you dry out the hydrate, you get plain old Fe_2O_3 .⁶

The need for dissolved oxygen in the rust process is easily demonstrated. You need two small pieces of clean steel and two glass jars, one with a cap. Fill one jar with water and drop in a piece of metal. This will be the "with oxygen" sample. Then bring some water to a vigorous boil and, with it, fill the second jar to the brim. Quickly insert the other steel sample and affix the cap.⁷ Set the jars aside for a day, and then examine the contents. The sample in the oxygenated water will have rust, while the other will not.⁸

What about stainless steel, why is *it* impervious to corrosion? Ordinary steel is an alloy of iron and carbon. Stainless steel is an alloy of iron, carbon, and chromium—lots of it. Chromium adores oxygen. Chromium atoms at and near the surface of stainless steel will quickly join with atmospheric oxygen to make chromium oxides, oxides that are essentially impenetrable beyond a certain depth, keeping additional oxygen away from the iron. This is an example of passivization. It is our metallurgical misfortune that rust does not, likewise, form an impermeable layer. It's fairly porous, allowing water to reach the

5 The formula $\text{Fe}(\text{OH})_3$, while correctly enumerating all the atoms in the molecule, does not describe the structure. There are *not* three hydroxyls individually bound to the iron. Chemical formulae often mimic molecular structure, but not in this case.

6 In a hydrate, water is mechanically trapped among the other atoms of the molecule. It does not bind with them chemically.

7 The higher the temperature of water, the less dissolved gas it can hold. That's why warm soda quickly loses all its fizz.

8 See color plates. The rust that forms while the metal is submerged is actually *loose* and will slide off easily. To become a noxious adherence, rust needs a chance to dry on the irregular surface below.

unrusted metal beneath. As the inner layer is attacked, the outer rust falls away the cycle begins again, and so the whole of steel civilization gradually disintegrates. And that's in *fresh* water.

In the absence of salt or similar chemicals, rust proceeds according to the above scenario, known as an *oxygen concentration cell*. In such a cell, the water has relatively few ions. If we introduce Cl^- from dissolved salt, corrosion will proceed apace. In a nutshell, the negative chlorine ions will pull positive iron ions away from the vicinity of the anode, accelerating the reaction. You can demonstrate the difference with two bowls, each with a pint of water and one with nine grams of dissolved salt (this approximates the salinity of seawater). Insert steel in both and wait overnight. The contrast will be dramatic.

The complete explanation of rust is long and complicated. I own a two-volume tome titled *Corrosion* by Lionel Shreir and others—a kind of Bible on the subject—covering corrosion of all sorts and the mitigations thereof. Though *Corrosion* is over three thousand pages long, the introduction to *Rusting in Water* [of iron and steel] begins thus:

The corrosion of steel by natural and industrial waters is a complicated and many-sided phenomenon, which cannot be dealt with completely within the narrow compass available here.

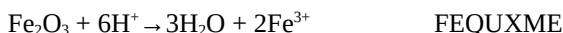
Admittedly, Shreir attributes the wide scope of the subject to the great variety of environments in which steel corrosion takes place, but in my own attempts to become conversant about plain-water rusting at room temperature, I have often found my head spinning. For those who want to delve into the details, a good place to start is a paper by John Rossum, *Fundamentals of Metallic Corrosion in Fresh Water*.⁹

* * *

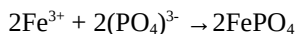
Ok, so the rust is on Andrew's tools. How to get it off? One option suggested to me was naval jelly. I pictured it as some chemical potent enough to take the brass off a battleship, but the stuff is not nearly so vicious. The active ingredient is phosphoric acid (H_3PO_4), the same chemical that gives "zing" to

9 <http://www.roscoemoss.com/wp-content/uploads/publications/fmcf.pdf>. Pages two through six are the most instructive.

Coca-Cola and dissolves your teeth. The jelly has a water base in which the acid molecules fall apart, losing one hydrogen after another to become a soup of hydrogen ions (H^+) and phosphate group ions $(PO_4)^{3-}$. FIXME TYPOGRAPHY When applied to rust, the loose hydrogens grab oxygen from the iron oxide to form water and iron ions:

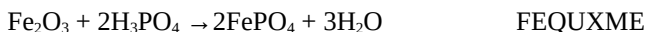


The phosphate groups assimilate the iron to become iron phosphate:



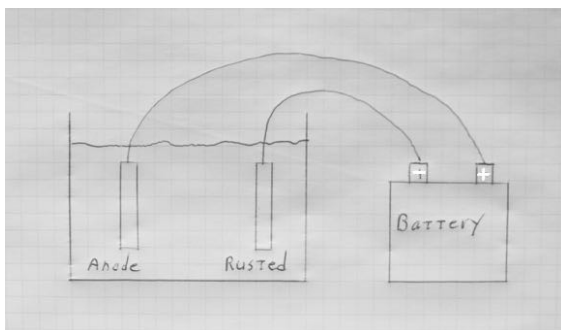
FEQUXME, FIXME TYPOGRAPHY

In a single equation, rust plus phosphoric acid becomes iron phosphate and water.



Iron phosphate dissolves in water, so you can just wash it off. Goodbye, rust.

Rust can also be removed in the process of *electrolysis*, by which water is electrically separated into hydrogen and oxygen, and the hydrogen used to our advantage. Consider the apparatus below, consisting of a battery, two iron-based objects (one rusted), with the artifacts placed in a water bath and connected to the battery.

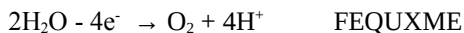


FIGSME Electrolysis for rust removal (electrolysis1.jpg)

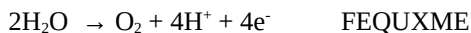
With the rusted object connected to the negative pole of the battery, electrons will flow into it (it's the cathode). The surrounding water molecules will take up one electron each and let go of one hydrogen, forming hydrogen gas and hydroxyl ions:¹⁰



Meanwhile, the anode pulls electrons away from water, sending them out the wire. It yields oxygen gas and hydrogen ions:



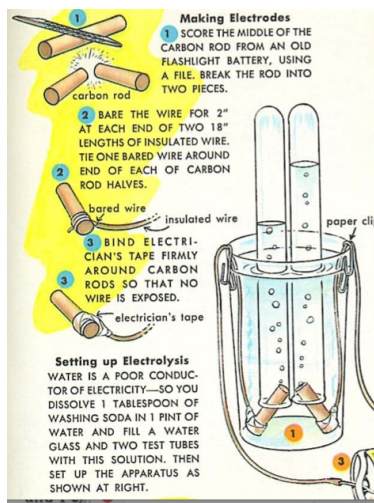
The above equation is more in the style of mathematics than chemistry, but I think it is clearer.¹¹ The chemist would write:



In chemistry class, one could collect pure hydrogen and oxygen by substituting carbon electrodes for the iron, and place inverted, water-filled test tubes over the electrodes. Gases released at the electrodes would bubble up into the tubes, displacing the water.

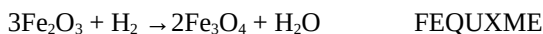
10 The water in the bath must contain an *electrolyte*, a chemical that separates into ions upon dissolving. These ions help convey electric charge between the cathode and the anode. Without an electrolyte, electrolysis would be very slow.

11 Since four electrons are liberated in the anode reaction, the cathode reaction equation is also written with four electrons for balance.



PHIXME Electrolysis from Golden Chemistry book (electrolysis.2png) REPLACE OR MAKE COLOR PLATE

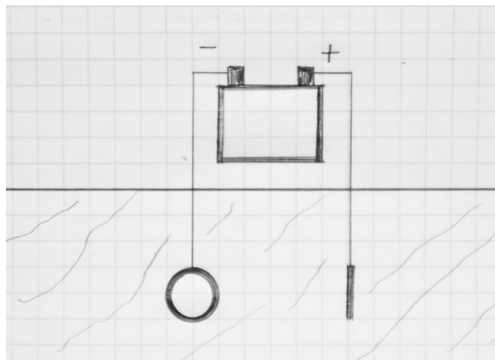
But we have bigger fish to fry. The hydrogen liberated at the cathode can be used to turn the red oxide (hematite) into black oxide (magnetite). Three reds become two blacks, plus some water created on the side:



As the reaction proceeds, the innermost layer of rust is converted into magnetite. When enough has formed, bits of it come loose, taking the covering of hematite along for the ride. Goodbye, rust.¹²

Since corrosion results from a destructive electric current, could we stop it with an opposing current? The answer is yes and the technique is known as *cathodic protection*. To protect some vulnerable structure, like a buried pipe, you need an electrode buried nearby and a current source. Conceptually, one could just stick a battery between the electrode and the pipe, as below:

¹² I used this method to clean up a chisel blade that had considerable rust.



FIGSME Underground pipe and electrode in protection circuit (underground.jpg)

The pipe, acting as a cathode, gains electrons from the battery in what is called the *impressed current*. Conversely, in the corrosion reaction the pipe is an anode, losing electrons in the *corrosion current*. If the impressed current is strong enough, it drowns out the corrosion current and the pipe is protected.

Another option is the *sacrificial anode*. It works by putting a vulnerable structure in electrical contact with something that corrodes in its place. Metals can be ranked in a *galvanic series*, a measure of how eagerly they will take electrical charge from each other.¹³ Iron ranks higher than zinc. When the two are placed in contact, electrons naturally flow to the iron, turning the zinc into an anode. A bridge of ferrous metal can be protected by clamping onto it blocks of zinc that waste away.

Your car's exterior sheet metal is probably plated with zinc, in a process called *galvanizing*. Zinc, exposed to the elements, develops a layer of carbonate that is highly resistant to corrosion.¹⁴ If the plating is damaged and the steel underneath becomes exposed, the remaining zinc will corrode preferentially as a sacrificial anode. The bodywork of the iconic BMW 2002 was not

13 This is related to electronegativity and it depends upon the chemical environment surrounding the metals.

14 That is, atmospheric oxygen cannot get past the carbonate to capture electrons. In the role of a sacrificial anode, zinc has its electrons snatched across the interface with the protected metal.

galvanized. Owners had the choice of moving to a desert environment or watching their precious motorcars dissolve.

Shreir said that corrosion is complicated, and I'll close with a detail I've skipped over. Different phases of steel (e.g.: ferrite and cementite) constitute slightly dissimilar metals with different galvanic rank. Adjacent grains of the two phases become anode/cathode pairs that enable the corrosion reaction all by themselves.

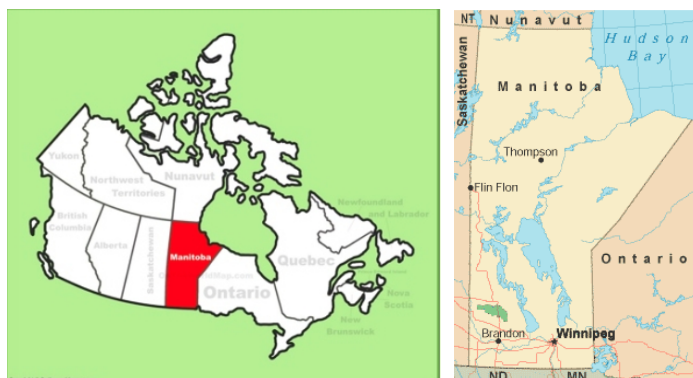
Steel is simply destined to rust.

Coming to America



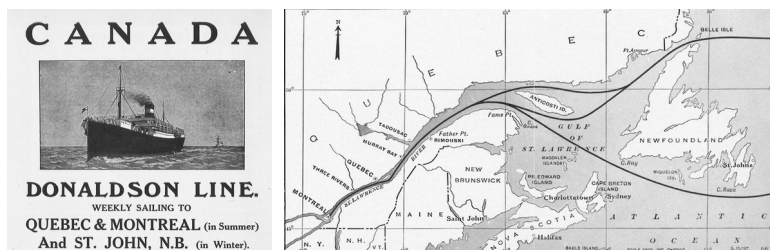
PHIXME Steamship Athenia promotional postcard (postcard.jpg)

19th century Scotland was a hard place to make a living. In June of 1880 the *New York Times* ran an article about the tenant farmers, subtitled, "Emigration their only hope." Over the generations, waves of Scots left for the less-peopled parts of the Empire (and former Empire). Andrew was not the first of his clan to take a departure. His Uncle Alexander emigrated to Australia circa 1838, and I am thus related to many of the Calderwoods on that continent. At times, inducements were offered to encourage people to start afresh across the sea. In the late 19th century, Canada was in want of farmers. Homesteads of 160 acres were made available to those who would improve the land and pay a recording fee of \$10. The Dominion Lands Act, under which the grants were made, was enacted in 1872 and continued in force in the prairie provinces until 1930. The province of Manitoba was (and is) a major region of dryland farming. Its capital is Winnipeg.



FIGSME REPLACE Maps of Canada and Manitoba

In Andrew's time, the steamship companies carried a considerable "trade" in emigrants to Canada. From April to November, the Donaldson Line ran four ships from Glasgow to Quebec¹ and Montreal and back: the *Athenia*, the *Saturnia*, the *Cassandra*, and the *Letitia*.



FIGSME Donaldson flyer and sea approaches to Quebec (advert.jpg, route.jpg)

The Calderwoods made passage on the *Athenia*. I knew this early on in my research because, in a miracle of genealogical serendipity, a passenger list survives among the family heirlooms. It identified the name of the ship, its departure date, and destination port. These facts were critical. When I started tracing Calderwood movements, the Canadian maritime immigration records

1 Also known as Quebec City.

However, that was a different *Athenia*. The vessel carrying my forebears was another casualty of warfare (also off of Ireland), but in 1917. After the Great War, the Donaldson Line gave the name to a new ship. Even dealers in nautical memorabilia confuse the two liners, and I once found an art gallery advertising a painting of the famous WWII *Athenia* that was, in fact, a portrait of its predecessor.⁵



PHIXME Four-berth cabin on *Saturnia* (World Ship Society collections) (4berth.png)

The Donaldson ships on the Glasgow/Quebec run had two-berth and four-berth cabins for the second-class passengers.⁶ The Calderwoods, being a party of eight, presumably took a pair of four-berth cabins. A 1909 letter from the MacKay Brothers shipping agent (of Edinburgh) quoted the cheapest second-class Donaldson fare from Glasgow to Montreal as £8 10s for a single person (Quebec was presumably slightly cheaper). So the family must have paid on the order of £64 total for the passage. Relative costs of the different cabins can be seen in this table of eastbound fares from a 1913 Canadian brochure:

deck	outside 4-berth	outside 2-berth	inside 4-berth	inside 2-berth
bridge	\$55.00	-	-	-
shelter	\$50.00	-	-	\$52.50
main	\$47.50	\$50.00	\$47.50	\$47.50

5 I explained the situation and offered half price, but they wouldn't budge.

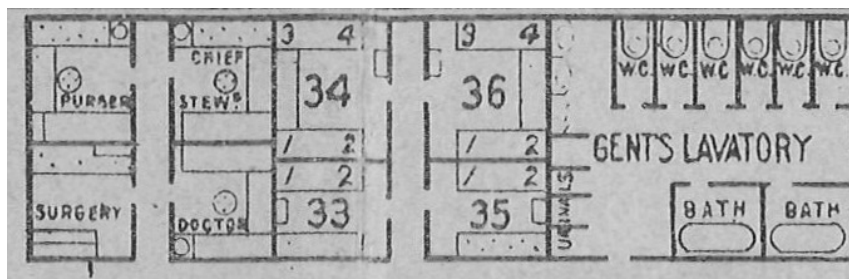
6 There was no first-class.

FIXME Stateroom fares per person, Quebec to Glasgow (Canadian \$. Under 12 years, half-price; infants, \$7.50)

The brochure has deck plans for the ships, and says this in regard to baggage:

...Each adult Cabin [2nd class] passenger is allowed 20 cubic feet;⁷ third class [steerage] passengers 10 cubic feet. Excess baggage is charged at the rate of twenty-five cents per cubic foot. Baggage should be alongside steamer not later than the day prior to sailing. Packages required for use on the voyage should not exceed 14 inches in height, 2 feet in width, and 3 feet in length [presumably the size of the "bins" in the cabins]. It is desirable that no single piece of baggage exceed 250 pounds in weight...

The four-berth cabins were approximately 10½' by 12' in size; the two-berth, 9' by 9'. The shelter deck included cabins for the purser, the chief steward, the barber, maritime cadets, and the doctor, as well as the doctor's surgery.⁸



FIGSME Part of Athenia "shelter" deck, showing passenger cabins 33-36 (shelter_zoom.jpg)

The main deck had private cabins for the chief engineer and the 2nd engineer. The 3rd engineer bunked with the junior 2nd engineer, the 4th engineer with the 5th, and the 6th engineer with the electrician. From the distribution of lavatories it appears the ship was expected to carry more men than women. This is also evidenced by the provision of a fairly large "Smoke Room" in comparison to a diminutive "Ladies Room," both on the bridge deck. Meals were taken on the shelter deck, and the cabin passengers were free to move about all three decks. Adding up the berths, there was room for one hundred

⁷ Andrew's tool chest, alone, was about twelve cubic feet.

⁸ The purser, steward, and barber presumably used their cabins for "business" as well as slumber.

fifty-four people in cabin-class transit. On the June 27 passage, the cabin headcount was ninety-nine, plus seventy-six in steerage.

The Donaldson sailing list called for ships to make Quebec eight days after leaving Glasgow, but they would first stop at Grosse Isle (Big Island) in the St. Lawrence for medical inspection. Passengers found to be afflicted with disease were taken to the quarantine station there, and the steerage portion of Athenia's immigration schedule shows seven individuals marked "Hospital." The Calderwoods arrived in Quebec on July 5th. That happened to be the 300th anniversary of the city's founding by Samuel de Champlain, and the population was surely in a festive mood. The shipping news of the next day's *Quebec Chronicle* noted the following:

Donaldson Line: Steamer Athenia, Captain McNeill, from Glasgow, with passengers and general cargo, arrived in port yesterday evening and moored at the Breakwater. She has a number of sheep and some cargo to land at Lewis.

The passenger schedule listed Winnipeg as the family's ultimate destination, and in this they were not alone. The scanned documents are hard to read, but I counted seventeen other immigrants in the cabins headed to the same city.⁹ Their listed occupations included: chemist (pharmacist), farm laborer, domestic servant, joiner, insurance agent, mechanical engineer, bricklayer, cigarette maker, farmer (e.g.: Andrew), carpenter, bookkeeper, butcher, shop assistant, and engineer.¹⁰ The schedule showed most arrivals making connections with the Canadian Pacific Railway, and the July 5th *Chronicle* had a full-page article about the new train station in Winnipeg:

Coupled with the marvelous growth of the west during the past ten years came a realization of the necessity for increased railroad facilities for handling the output of the greatly increased acreage under cultivation. It was a task which only big men could handle, and one which, improperly handled, might easily mar the future of the country. Transportation adequate to the needs of the country could not be developed along the same lines as in a country of more extensive farming. It needed railway facilities ahead of the settlement, railways which were in readiness to

9 The next most popular destination was Vancouver.

10 Steerage occupations included: farm laborer, railroad laborer, domestic servant, grocer, weaver, brass finisher, carpenter, joiner, horseman, machinist, fireman, clerk, mason, designer, bookkeeper, c[hild?] nurse, factory worker, ploughman, fitter, draughtsman, stableman, painter, and miner. Only seven steerage passengers were headed for Winnipeg.

handle the wheat as soon as it was threshed, and the people of the west demanded in no uncertain voice that their needs should be met...

...The basement floor will be 15 feet below the level of Main Street. The entire north wing of this floor will be devoted to immigrants. There will be a waiting room, area 1,000 square feet, having a lunch counter on the north side and a laundry and separate men's and women's bathrooms on the east side. Adjoining the waiting room on the south side will be a separate men's smoking room, with toilets, area 3,000 square feet...

Winnipeg was a boom town, but the Calderwoods did not stay there. The explanation passed down to me was that one of the family members was diagnosed with a heart problem. The doctor recommended relocating to Portland, Oregon, where the climate would be more agreeable. What a jolt it must have been to abandon the expected agricultural prosperity of the wheat fields of Manitoba and head for the unknown in Portland.

They would once again travel by the Canadian Pacific. Daughters Anne and Mary were the first to go, arriving in the U.S. on September 1st with \$20 between them. Andrew Jr. followed eight days later with \$30 in his pocket. Andrew, Maggie, Robert, and Peggy came in November, carrying \$700. John's movements are less clear.¹¹ The border crossings appear to have taken place at Eastport, Idaho.

Once the family was in Portland, I could follow them in the city directories. In 1909 only Mary appears. She was a domestic servant in the employ of a family on Northrup St., a situation that my father said must have been very sad for her. The following year most of the family is shown at a residence on Market St. Eldest daughter Anne was then living as a servant elsewhere, but Mary was listed at home. Andrew Sr. had become a clerk at the Meier and Frank department store. Andrew Jr. worked as a bookkeeper for the Oregon Mortgage Company and my grandfather, Robert, had landed a job as an office boy at Oregon Life Insurance. By 1911, everyone had moved to nearby 10th St.¹² The family would stay there for at least six years.

11 All this analysis required decoding some almost unreadable immigration forms. There is a confusing record regarding a re-entry by a John Calderwood in 1911, which states that he had been in the United States since 1907. When Andrew cleared U.S. in immigration 1908, he said that his son John was in Griswold, Manitoba.

The children started working their way up in the world and slowly moving out of the nest. Anne and Mary enrolled at a business school, where they presumably trained for stenography and other office work. Peggy was still too young for a job, which was a blessing since that made it possible for her to attend high school. The kids who had reached the age of thirteen in Scotland got no more public education there and they started working immediately in America. Andrew lived with his shrinking at-home family until 1919, moving two more times. When he died that year, he was employed as a watchman for Meier and Frank, and had spent four years or more as a warehouseman there. The progress of the father and the (working) children is summarized below:

	Andrew	John	Anne	Andrew Jr.	Mary	Robert
1909	-	-	-	-	domestic	-
1910	clerk	-	domestic	bookkeeper	?	messenger
1911	whsman	whsman	maid	bookkeeper	seamstress	clerk
1912	whsman	whsman	steno	asst. cashier	seamstress	clerk
1913	whsman	whsman	steno	asst. cashier	student	clerk
1914	?	clerk	steno	asst. cashier	steno	clerk
1915	?	whsman	clerk	asst. cashier	steno	clerk
1916	whsman	clerk	clerk	asst. cashier	steno	clerk
1917	watchman	-	steno	asst. cashier	steno	clerk
1918	watchman	-	steno	-	steno	-
1920	-	-	bookkeeper	asst. cashier	steno	cashier

FIXME Family progress (no separate data for 1919) Legend: - = not listed, ? = no occupation given

Robert had got his job after answering a January 14, 1909 advertisement in the *Oregonian* newspaper:

BOY about 15 for insurance office, opportunity for advancement; must live at home. Address in own handwriting.

12 Neither dwelling survives. Portland revised street names and numbering in the 1930s. All addresses given here are of the old style.

There was, indeed, opportunity for advancement. At his retirement, Robert was the corporate secretary and vice-president of personnel for what had become the Standard Insurance Company of Oregon.

The careful reader will have noted that the story so far does not include Andrew's second son, George Calderwood. What happened to him? George came to Canada before the rest of the family and would remain there as a successful farmer. The details of his travel were unknown, however, and it seemed impossible to find his arrival in the immigration records. But hope springs eternal, and I found myself thinking along these lines: he probably came a year or two earlier than the others, he would surely have sailed from Glasgow, and very likely on one of the Donaldson steamers. The immigration schedules were indexed not just by ship name, but by shipping *company*. It was easy to call up schedules for all the Donaldson vessels that arrived in Quebec in 1907, and I began to go through them, expressing silent gratitude to those pursers who drew up their passenger lists in alphabetical order (and cursing those who did not). For the June 17 arrival of the *Cassandra*, I found him: Calderwood, Geo. R, age 19, farm laborer, destination Winnipeg.¹³ By the time the rest of the clan arrived, George was engaged to marry Catherine Baird, an Irish immigrant, and the wedding took place mere weeks after his parents and siblings set foot in Quebec.



13 I also found a curious, very short immigration schedule for a Donaldson ship that appeared to be a *cargo* vessel. It had five stowaways!

PHIXME Andrew's last home, on Glenn Road, Portland (pdx_house.jpg)

Andrew became a U.S. citizen in 1916. His naturalization certificate has him 6' 2" in height, with fair complexion, grey eyes, and sandy hair. Son Robert became a citizen via army service during the war. He trained in North Carolina, but never made it to Europe. While Robert was in the South, Andrew wrote a birthday letter to *him*, that was a curveball to *me*:

My Dear Bob:

Well here I am at home still nursing this old Lumbago, Sciatica combination. Sometimes I feel pretty good & 2 or 3 times I have made arrangement to go down to the Works to see some of them about coming back in a day or so when the old thing would come back again & I was nearly as bad as ever. Some days I can walk not so fast & other days I can't bear my weight on my legs. Just now I am taking osteopathic treatments & was getting along satisfactorily until last Monday night. The Dr. overestimated my strength & gave me a treatment for the dregs of the Lumbago he always held off until I was strong enough. But that is where he and I were deceived as I did not have strength enough, with the result that Tues. & Wed. I was not able to get out of bed & the pain was bad. However the Dr. says it will just take a little longer. Well, here's hope for the best as I am pretty well sick of it. I hope you will excuse my writing with the pencil as my hand has got so shaky I can't work the pen. Well Bob, I wish to congratulate you on your Birthday & "Many more may ye see." Hadst I been working & making big shipyard wages I meant to send you something more substantial than mere congratulations. Edna & the children went down to Jack's[?] yesterday morning & Andrew [jr.] is going down on Sat. & all coming home on Sunday. Andrew takes his examination for citizenship tomorrow. I think he will be glad when it is all over. Love to Hugh if he is there & love to your dear self from all here.

Father. August 16 1918

"Shipyard wages"—what was he talking about? The city directories show him working for Meier and Frank. The letter provoked a research segue into Portland history.

The City of Roses lies astride the Willamette River, the westernmost major tributary of the Columbia. As the practical limit of upriver shipping on the Willamette, Portland became the center of commerce as the transportation hub closest to the farms of the fertile Willamette Valley. Where there is good timber and navigable water, shipbuilding is sure to follow, and by 1900, Portland was turning out both wooden and steel vessels, though not in great numbers. The first world war changed that, if only temporarily. In response to the sudden

demand for ships after America entered the conflict, Portland, along with other West Coast cities, experienced a maritime construction boom. I was able to find copies of *Pacific Marine Review* from that era, and they shed light on the particulars. The July 1918 issue touted the following comparison of shipbuilding in Oregon before and during the war:

Statistic	December, 1916	June, 1918
Shipyard employees	4,200	32,350
Monthly payroll	\$302,400	\$3,493,800
Ships under construction	11	94
Tonnage under construction	48,000	370,400
Value of construction contracts	\$22,250,000	\$200,000,000

FIGME Portland shipbuilding statistics

There would certainly have been new employment opportunities at the yards, but where would Andrew, at age sixty-three and no shipyard experience, fit in? There *were* wooden ships under construction: otherwise-modern vessels with wood hulls.¹⁴ Andrew's skill as a woodworker could have played towards that. But he referred to "The Works" and that appeared to be the Willamette Iron and Steel Works (WISW), a builder of metal ships. It was an incredible puzzle.



14 Don't laugh—huge old-growth timber was still available at that time.

PHIXME Willamette Iron and Steel Works (right side, with barges; Oregon Dry Dock at left). Undated anonymous photograph, courtesy Oregon Historical Society (#bb011482).

In the spring of 1919, Andrew had been working for Meier and Frank. A wartime job could have easily ended by then, so it would be no surprise to find him back at the department store. The city directory of 1917 had him there, too, but that directory would have been compiled in late 1916, so it would not have caught the industrial mobilization of the next year. Andrew could easily have left the department store and taken a new job in the interim. I was doing my research at the Oregon Historical Society library, and they didn't have a 1918 directory. It seemed I was stymied in learning his occupation for that year. For lack of anything better to do, I began to simply read all of the 1918 issues of *Pacific Marine Review*. It was a trade rag, with a fairly hefty page count. My jaw dropped when I found an obscure article about teak (emphasis mine):

*...The oil in the wood resists the entrance of water into the grain and prevents it from becoming water soaked, even when long exposed to submersion. One of the important characteristics of the wood, however, is its low free acid contents, which feature, in connection with its oily nature, prevents corrosion of iron and steel when placed in contact with the wood. These are such important qualities in teak that no other wood is used on warships for decking, armor plate backing, **joiner work**, etc. ... we should use this most remarkable wood extensively and add largely to the long life of our new merchant marine...*

Metal ships had wooden appointments: probably cabinets, counters, doors and the like, and the shipyard would have had a joinery shop to make them. Was it possible that Andrew was plying his old trade again? I don't think so, but I can't rule it out completely. I eventually located a 1918 Portland directory at the public library in Seattle. It listed Andrew as a watchman, but, maddeningly, it didn't say where. There were two possibilities: he was at WISW as a watchman or the directory hadn't been properly updated for the new year. The combined 1919/1920 directory was no help, apparently having been compiled at the end of 1919, after Andrew had died (it listed Maggie as a widow).

The clues don't fully add up. Was Andrew just being facetious about "big shipyard wages"? Watchmen were not getting rich. And would he really have left one watchman's job for another? It might have been physical labor at

WISW that brought on his back problems. Even if he was far past his prime, the wartime labor shortage might have created jobs openings for less-demanding shop work. I will likely never know for certain if he again picked up the plane and chisel, but it's nice to imagine that it could have happened.

Iron from the Stars

The Smithsonian Institution is best known for its national museums in Washington, D.C., but it also operates two scientific facilities: the Smithsonian Tropical Research Institute and the Smithsonian Astrophysical Observatory. For nearly ten years I worked at the latter, known, for short, as SAO. The observatory has grown from modest beginnings in 1890 into one of the premier astronomical research organizations. Along the way, it became one half of a joint venture with Harvard College Observatory, in a marriage known as the Harvard-Smithsonian Center for Astrophysics.¹ I joined SAO in 1997 as a software engineer in the High Energy Astrophysics Division to work on data processing for the Advanced X-ray Astrophysics Facility, a NASA satellite that would later be known as *Chandra*.

Going to SAO was a career risk. I had a steady job at a more conventional technology firm, but I was tired of it, and astronomy had been a major interest of mine since childhood. "Uncertain" is the watchword of all space missions, and the fellow who hired me cautioned that I just had to trust that everything would really come together (the next year, he left). The road to orbit was, indeed, a roller coaster, and as the liftoff date kept slipping into the future, we joked about having an *annual* one-year-to-launch party.

In July of 1999, after two aborted countdowns, the shuttle *Columbia* finally got our observatory into space. *Chandra* has been a big scientific success, but compared to the spiffy images from *Hubble*, the pictures it returns are much harder for the general public to interpret, so it doesn't get much press attention. Early in the mission, NASA would stage "Space Science Update" events where members of the news media could quiz a panel of scientific luminaries about the new discoveries, but only one or two journalists would show up.

While working at SAO, I kept a big poster of the Periodic Table of the Elements in my office. Astronomical X-rays are emitted in the throes of great violence, such as supernova explosions. These stellar catastrophes are prodigious distributors of the chemical elements synthesized both before and

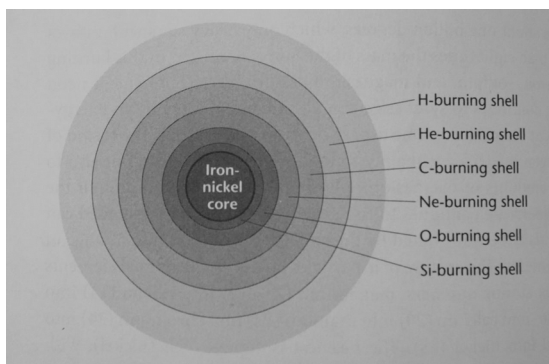
1 Recently re-branded as *Center for Astrophysics, Harvard and Smithsonian*.

during the star's demise. One of the major sources of X-rays in supernova debris is superheated iron.

* * *

Stellar life begins with the fusion of hydrogen atoms into helium. It happens in the core of the star, where pressure and temperature are both at their peak. The more massive the star, the higher the peak. Massive stars "burn" their hydrogen furiously, so that the extra fuel actually cuts their lifespan. A small star like our Sun is a less voracious nuclear furnace, so it lives much longer than giant or supergiant stars. But whatever a star's mass, its core eventually fills with so much helium that hydrogen fusion cannot continue there.

Gravity creates the conditions for fusion. As the diffuse gas cloud of a star-to-be slowly contracts under gravitational force, it heats up. When the core ignites, energy flowing out from the center balances the gravitational contraction and the star becomes stable. With the end of hydrogen fusion, gravity asserts itself again. The star contracts and the core temperature rises to start new fusion reactions: helium into carbon and oxygen. If the star is massive enough, it will become a Periodic Table sampler, as one core after another sputters, contracts, re-ignites, and starts fusing heavier elements from the nuclear ashes of the previous core.



FIGSME Late-life cross section of massive star [REPLACE]

A big star will progressively burn hydrogen, helium, carbon, neon, oxygen, and silicon, also producing sodium, magnesium, sulfur, iron and nickel along the way. But silicon fusion (yielding iron and nickel) is the end of the line. No

energy can be released by further fusion, and the star's "meal" of silicon is a feast of doom. As the iron and nickel pile up, the core becomes more dense and is compressed under its own gravity. Atoms show tremendous resistance to being squished together, but this refusal is not absolute. With no energy outflow to help in the fight against gravity, the core eventually succumbs to it. Collapse ensues, with a rebound that rips the star apart.²

A not-entirely-well-known fact is that the iron and nickel in the core do not survive the supernova event. In the inner core, collapse drives all the atomic electrons into their respective nuclei. There they combine with the protons, creating neutrons. The atoms, as such, cease to exist. In the outer core, iron and nickel caught in the rebound shock undergo *photodisintegration*, turning back into subatomic particles. The iron we find in a supernova remnant is not the end product of the fusion layers, but a side effect of the outgoing shock wave.³ When the rebounding blast hits the silicon layer it is still strong enough to shatter some of those large atoms back into helium. In this high-energy soup, the remaining silicon can transmute into heavier elements by "capturing" helium nuclei (known as *alpha* particles) in the following progression:

stage	base element	plus He yields
1	silicon	sulfur
2	sulfur	argon
3	argon	calcium
4	calcium	titanium
5	titanium	chromium
6	chromium	iron
7	iron	nickel
8	nickel	zinc

FIGURE Alpha-capture series from silicon to zinc.

And so we get our iron.⁴ Such is the culmination of a *core-collapse* supernova, also known as a "Type II" supernova—probably the kind of stellar

2 Collapse is often attributed to the star "running out of fuel." No. An overweight core is the cause.
3 Well, a little bit of core iron can survive.
4 Also, much of the nickel produced is radioactively unstable. It decays into iron.

explosion foremost in the popular astronomical imagination.⁵ A noted Type II supernova, or rather, its remnant, is found in the constellation of Cassiopeia,⁶ and is known as *Cassiopeia A*, or *Cas A* for short. It was the first observational target of the Chandra X-ray Observatory.

When astronomers activate a new telescope, all sorts of engineering tests take place to make sure the equipment is working properly. But when everything appears in order, the time comes for *first light*. This is the first scientific image from the instrument, and it is awaited with mixed excitement and terror. *Chandra* was beyond the reach of astronaut servicing, so any flaws in the satellite were unfixable. Furthermore, there had been a kerfuffle after launch when *Chandra* wound up very slightly below its nominal orbit. Though the trajectory was still within specifications, some news outlet announced that a NASA satellite had failed to reach altitude. After this, there was a general lockdown on disclosing details of the commissioning process, even within SAO. But as the first-light data of Cassiopeia A were received, the activation team needed technical assistance from my software group. Thus, we got a pre-release view of the image.⁷



PHIXME First-light image (contraband1.jpg)

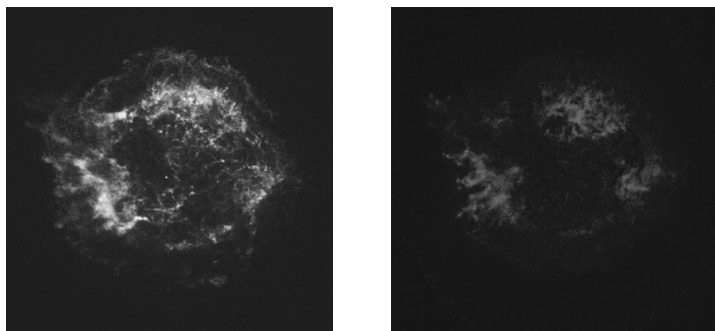
-
- 5 The full story is more complicated. A star of more than 10 times the mass of the sun finishes its life like this. A star of 8 to 10 solar masses does not form an iron core, but it still collapses and makes iron in the supernova rebound.
- 6 Pronounced *CASS-ee-oh-pee-uh* or *cass-ee-OH-pee-uh*, take your pick. Cassiopeia is located in the northern sky, and the bright stars form a slightly warped letter W.
- 7 All the *Chandra* images here have had some level of adjustment for best presentation. The (public) originals are available at chandra.harvard.edu.

It was excellent. As of this writing, *Chandra* has been operating for twenty-one years, and Cassiopeia A has been observed repeatedly. In the data, astronomers can actually *see* iron, as well as other chemical elements. To explain how, we must return to atomic structure.

The atom, as we have seen, has clouds of electrons whirling about the nucleus. In chemical reactions, we watched atoms lose an electron or two and become *ionized*. It takes energy to pull off these electrons. In a test tube, not a whole lot of energy is available, so only loosely held electrons are readily removed. But for atoms caught in the violence of a supernova explosion, electrons are stripped away in abundance. Upward of two dozen electrons can be knocked from an iron atom. When loose electrons later recombine with a host atom, the energy they acquired during ejection must be released, and this energy contains clues about the identity of those atoms.

The process of ejection and recombination of electrons in a supernova remnant is essentially the same as what happens in a neon tube. There, high voltage is used to excite the atoms of neon gas. Electrons absorb the energy and jump off. When they recombine with the atoms, the electrons must surrender that extra energy. They do so by emitting light of a red color characteristic of neon.⁸ When such "free" electrons recombine with iron atoms, there is a light emission that is characteristic of iron. A particularly potent photon comes from the sixteenth stripped-off electron as it later recombines. Rather than red, or blue, or even ultraviolet light, the emission comes as X-rays, and *Chandra* can see them. Though X-ray photons of many different energies emerge from a supernova, *Chandra* can sort them out and astronomers then trace some of them to individual chemical elements. Below, X-rays from Cassiopeia A show the presence of iron.

8 Actually, several "shades" of red.



FIGSME Cassiopeia A. Left: all X-ray light, right: iron X-rays. NASA/Chandra X-ray Center/SAO (first_light_mono.jpg, casa_iron_mono.jpg)

But most of the iron in Andrew's steel blades likely did not come from a core-collapse supernova. When a "Type II" class of *anything* exists, you can bet there is also a Type I, and it is this (very different) kind of stellar explosion whose iron product dominated the contents of the crucible furnaces at Sheffield.⁹

* * *

Most stars are not massive enough to go through the whole fusion chain to iron. After helium fusion stops, the carbon/oxygen core cannot contract enough to start new reactions, much less proceed to collapse. What's more, the end of fusion in stars of modest mass is followed by the dissipation into space of the envelope of gas surrounding the core, forming a potentially beautiful planetary nebula. With no more energy in production, the star—known as a white dwarf—simply fades away, keeping its few synthesized elements largely to itself.

Unless, that is, the star has a partner. Our Sun has multiple planets for partners, but many stars have *other* stars for companions. Systems of two, three, or more stars orbiting a common center of mass are quite common, and therein lies the opportunity for a white dwarf to play the supernova game,

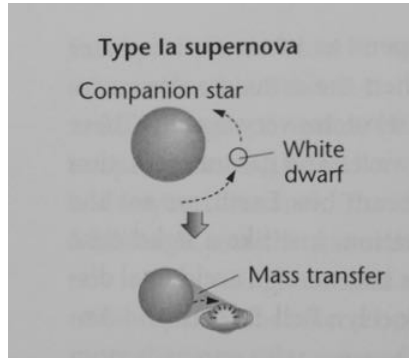
9 Scientists Francesca Matteucci and Cristina Chiappini posit that Type I supernovae are responsible for 70% of iron in the solar neighborhood, with Type II providing the rest. See *Interpretation of Abundance Ratios* in Publications of the Australian Astronomical Society, March 2005.

albeit under different rules. While a core-collapse supernova gets most of its explosive energy from gravity, a Type I, or *thermonuclear* supernova, is powered by sudden, violent fusion incited by new mass acquired from a partner. Type I supernovae (in particular, subtype Ia) have acquired fame as the "standard candles" used to measure distances and to infer the accelerating expansion of the universe.

Astronomy is plagued by the eternal question, *How far away?* Establishing reliable distances to objects outside of the solar system is a persistent challenge. Long ago, astronomers thought all stars probably put out the same amount of light. Therefore, a star that appears dim must be farther away than one that appears bright. This, of course, was wrong, and astronomers since then have spent generations painstakingly staking out actual distances to stars and galaxies. But it turns out that all Type Ia supernovae *are* about equally luminous: the dim ones really are farther and the bright ones nearer.¹⁰ This was the key enabler of the measurements of cosmological expansion. The fortunate uniformity exists because there is an upper bound on the mass of a white dwarf and, hence, a constraint on the amount of energy it can release as it explodes. This mass limit is—aha—the same kind of thing we saw in Type II: an inert core can only support itself against so much gravity.

In close orbit with another star, a white dwarf can potentially capture gas shed from the outer layers of its companion. This material starts out orbiting the dwarf in the shape of a disc, and finally falls onto the surface in a process called *accretion*. By this process, the dwarf can grow. The original strength of gravity in a white dwarf is limited—after all, its progenitor didn't have enough mass to start more reactions. But as the dwarf gains mass from another star, its gravity gets stronger.

10 Probably.



FIGSME Accretion by white dwarf star [REPLACE]

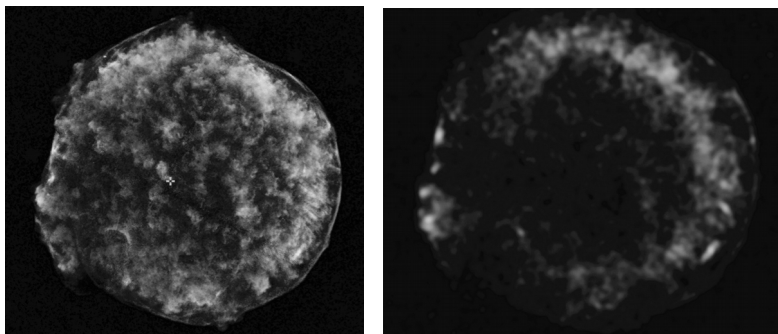
The Indian physicist Subrahmanyan Chandrasekhar, for whom the *Chandra* satellite is named, determined the upper limit of "dead" matter that can hold its own against gravity: about 1.4 times the mass of our own Sun. When a white dwarf accumulates enough material to exceed this bound, gravity induces runaway fusion in the center of the star, synthesizing a particular mixture of new elements.

The matter in a white dwarf is packed so tightly as to defy the imagination. By comparison, the matter in a living star is rarefied. These stars need highly energetic collisions between the atoms to get fusion, and these impacts are relatively few and far between. But when a white dwarf starts fusing carbon, the extreme density of the newly heated matter enables just about *any* fusion reaction to take place.¹¹ In a Type II progenitor, the making of iron had to await creation of a silicon layer from whose fusion it could form. But in the white dwarf ignition, iron can emerge directly from carbon and oxygen. Indeed, the whole "iron group" of elements (nickel, iron, chromium, manganese, and cobalt) are produced in abundance, with nickel and iron predominant.

A famous example of Type Ia supernovae lit up the northern sky in 1572. Bright enough to see in daylight, it caught the particular attention of Danish astronomer Tycho Brahe, who wrote about it and whose name now stands

11 Some fusion processes are still much more likely than others. The environment for this wild reactivity is called *nuclear statistical equilibrium* or NSE. NSE also occurs in the silicon layer of a Type II supernova, the alpha-capture chain being one consequence.

associated with it.¹² *Chandra* has been repeatedly pointed to Tycho's supernova.



FIGSME Tycho's supernova remnant. All X-ray light (L), and iron X-rays (R). Cross at left indicates explosion site based on combined radio and X-ray data. NASA/Chandra X-ray Center/SAO (tycho1_mono.jpg, tycho_iron_mono.jpg)

Though the accretion scenario is perfectly possible, hard evidence for it is difficult to come by. Lacking that evidence, there is a competing model for Type Ia: the white dwarf's companion is a second white dwarf. The pair spiral together and merge, and the unified mass goes over Chandrasekhar's limit and explodes. Since there is no friction in space, the stars must radiate away some of their gravitational energy to effect the in-spiral. Recent results from gravity-wave detectors, such as the LIGO system,¹³ have shown that pairs of black holes or neutron stars can merge in just this way.

A white dwarf is an example of *degenerate* matter, stuff that has been squeezed tight to the barriers imposed by quantum mechanics. A Type Ia supernova having one white dwarf is called *single-degenerate* (SD), while the two-dwarf scenario is known as *double-degenerate* (DD). A convincing way to identify a single-degenerate supernova would be to find its companion. Violent as supernovae are, they are not so destructive that companion stars (known as "donors") would likely be destroyed, and astronomers have tried looking for

¹² *De Nova Stella* (The New Star). The explosion is also known as "SN 1572."

¹³ Laser Interferometer Gravitational-Wave Observatory, based in Louisiana and Washington.

them. The quest for a Tycho donor can be followed in the scientific literature, and I offer the following synopsis as a peek into astrophysical research for those who have never seen it up close.

The fun began in 2004 when researcher Pilar Ruiz-Lapuente and colleagues published a paper describing their search for a companion to the star that blew up.¹⁴ Ruiz-Lapuente went looking for a possible donor using the William Herschel 4.2-meter telescope in the Canary Islands. Such a star should have two special properties. First, it should be near the center of the remnant. Second, it ought to be moving unusually fast. The team investigated thirteen stars and came up with one, "Tycho G," as a possible companion.

Other astronomers then began to chime in. In 2005, Klaus Fuhrmann suggested that Tycho G might be a interloper passing through the region of the supernova, but his theory didn't seem to catch fire. In 2007, Yutaka Ihara and others released data from the much bigger 8.2-meter Subaru telescope in Hawaii.¹⁵ They used a spectrograph to minutely examine the light from candidate stars, looking for indications of chemical elements. The year before, Jin Ozaki and Toshikazu Shigeyama pointed out that since a supernova makes a lot of iron—iron that winds up in the remnant—the light from a star inside the remnant could shine through the iron atoms and be imprinted with the spectral signature of that element. Detection of that signature would be compelling evidence. Tycho G, Ihara claimed, did not show such an imprint, but another star, Tycho E, did. Furthermore, E was considerably closer than G to the presumed center of the remnant. While not rejecting G outright, Ihara clearly preferred E as the donor.¹⁶

Two years later (2009), Ruiz-Lapuente returned with Jonay Gonzalez Hernandez and others, publishing their own spectroscopy of the light from Tycho G. While Ihara had analyzed the chemical imprints of the gas that G's light shone *through*, this new study examined the imprints made by G's own atmosphere. These data were gathered with a yet larger telescope, the 10-meter Keck instrument, also in Hawaii. If G was near to the supernova, it should have picked up some of the explosion products and incorporated them into its own

14 A list of Tycho supernova research papers is in the bibliography.

15 Subaru is the Japanese word for "Pleiades." The badge on the grille of Subaru cars is a stylized rendering of the six brightest stars of that asterism.

16 Failure to detect the iron imprint did not automatically disqualify Tycho G.

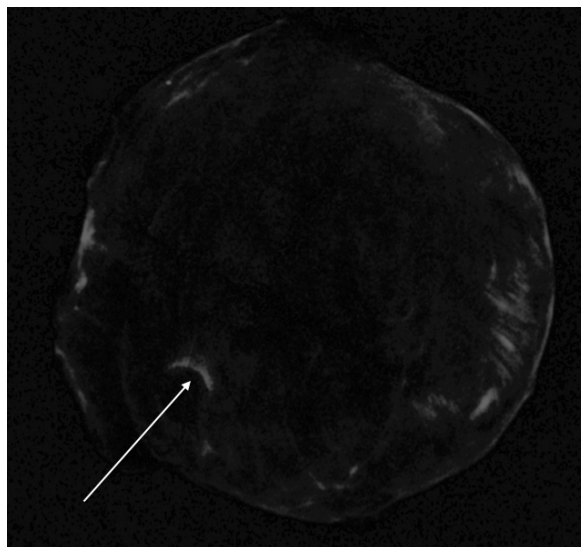
envelope, enriching whatever chemical composition the star naturally had. While the Keck spectrum showed no signs of iron enrichment, it had an excess of nickel, another supernova product.

The 2009 team also noted that the center point of the remnant was not well determined. For instance, parts of the debris wave have apparently collided with a large interstellar gas cloud, distorting its overall shape. And radio and X-ray images, though each showing a fairly symmetrical outline of the remnant, did not agree on its geometric center. Hence, Tycho G should not automatically be presumed too distant from the explosion site.

In 2008, Wolfgang Kerzendorf had reported an upper limit of only about 7.5 km/sec for G's rotation speed and noted that only a special sort of star would fit that bill.¹⁷ Gonzalez Hernandez and Ruiz-Lapuente countered (in 2009) that slow spin was not a problem. They also suggested that Ihara's data were not robust enough to support his 2007 conclusions.

After these discussions of the distance, motions, and spectrum of Tycho G, a new idea based on *Chandra* data came out in 2011. Fangjun Lu and others noticed something in the high-energy images: an arc of X-ray emission bending away from the supernova center. Compared to other energetic features, it was placed considerably within the remnant, rather than on the periphery.

17 Final version of this paper did not come out until 2009.



FIGSME High-energy X-rays, with arc noted (NASA/Chandra X-ray Center/SAO (tycho_shadow_mono.jpg))

Lu reasoned that this arc was material blown off the donor star during the explosion and he identified an X-ray "shadow" between the far side of the arc and the southeast (lower-left) edge of the remnant.¹⁸ This region had a general lessening of X-ray intensity, explainable by the arc having blocked a significant amount of debris from reaching that area.

In 2013, Kerzendorf, with new collaborators, reported new data from Keck that showed Tycho G with no detectable rotation, and no meaningful excess of nickel. Moreover, their own distance estimate for the star placed it *behind* the remnant.

Luigi Bedin, Ruiz-Lapuene, Gonzalez Hernandez, and others reanalyzed the earlier measurements of nickel and, in 2014, still concluded that there was an excess, though not so large as previously thought. They also posited a rotation speed so slow that measurements with available instruments would not detect it.

¹⁸ Astronomers like to display their images with east on the left side.

The next year, Zhichao Xue and others published a new determination of the explosion site, made by two very different methods. One approach was to use the positional data of Tycho Brahe and his contemporaries. The 16th century was still an age of *visual* astronomy. Astronomers measured positions in the sky using tools that were relatives of the sextant. Tycho was an excellent mechanical designer. He built instruments that were capable of unprecedented precision and he understood how to use them to best effect. Tycho and other astronomers repeatedly checked the position of the supernova with respect to other stars, and those measurements have come down to us. Xue computed the supernova position by a more comprehensive analysis of those measurements than had been previously tried.

The second estimate was based on X-ray data. As noted before, the debris wave ran into existing gas that slowed its progress in some directions. Using estimates for the density of that material, along with *Chandra* and radio measurements of the remnant's growth over the years, a mathematical model was worked backwards to a presumed explosion point. This point, in reasonable agreement with the 1572 data, placed the supernova center a considerable distance from previously-considered origins. The upshot was that Tycho G was much too far from Xue's computed center to have been in orbit with the white dwarf.

As of this writing, the status of Tycho G is still unresolved, and astronomers cannot yet point to any Type Ia supernova that is conclusively proven as single-degenerate. Think of the scientific literature as a meeting room where the Tycho astronomers come together every so often. They bring their latest data and theories about their data, and present them as if to a jury. They may receive support or challenges (or both) from the assembly, as the participants scrutinize each other's contributions, looking for breakthroughs or blunders. The astronomers labor under a huge difficulty: none of them can travel to the supernova remnant and look around. They must gather limited clues from a great distance and make assumptions about parameters of the object that cannot be reliably measured. Astronomers work with their clues, their assumptions, and their mathematics to see where the threads lead. Many dead ends may follow, but clarity eventually emerges—often through new instrumentation—and the community will reach consensus. That's how difficult science gets done.

Coda



PHIXME "Nanny" and Andrew in Portland

In 1909, when the Calderwood family fully threw themselves into becoming Americans, Oregon had been a state for only fifty years. They could have rubbed shoulders with pioneers who came on the wagon trains. About that time, the maternal side of my family was also setting up shop here. My great-grandfather Albert Westgate homesteaded in Umatilla County in the eastern part of the state, gaining his land grant in 1906. When I was a kid, his son Alfred, my grandfather, would take me trout fishing on the old ranch.

After thirty-five years in New England, I have come back to Oregon to make my own kind of new start in an unexpected early retirement. In the years I was away, the population boomed. There is major urban sprawl, much-degraded air quality, and sadly dysfunctional politics. But the Pacific Northwest still retains a taste of the freshness that my great-grandfathers found when they arrived here a century ago.

Andrew died on the 17th of June, 1919. His death certificate indicates that nephritis, a kidney disorder, was the cause of death. The physician signing the certificate stated that he had attended Andrew since the previous June, and had last seen him alive on the 15th. I cannot help but wonder what he thought as he

lay dying, four thousand miles from the place of his birth. His journey seems, to me, incredible. Andrew's life in Scotland was not easy, but he was no struggling crofter. He was born into a family that had social and economic standing in East Kilbride, and he received the hands-on mechanical and business education such a family could provide. He spent years as an amateur militiaman—a role he must have enjoyed—rising in rank and becoming an excellent rifle shot. He also excelled at lawn bowling as a member of the East Kilbride Bowling Club, winning a championship there. He didn't live on the margins of society. But at fifty-nine, he packed up his family and headed for the New World. Working the Rigghead dairy farm was surely a tall order, but starting from scratch on a distant continent would be no picnic. And at his age he could not reasonably expect to build enough new wealth so as to enjoy real ease before his death.

Andrew could have let the clock run out in East Kilbride, but had he done so, Anne, John, George, Andrew Jr., Mary, Robert, and Peggy would have had no future. Even if someone had continued at Rigghead, they'd have needed a family of laborers to run it. With all the hazards of inferring the intentions of those living long ago, I will say that Andrew crossed the Atlantic for the sake of his children.

Looking back at the Thanksgiving dinners of my childhood, where three of those children were always present, it seems, again, incredible that seventy years before, they had taken their holiday meals 'round a table in a rented Scottish farmhouse where the living was not nearly so good. Mary, Robert, and Peggy had done well for themselves, showing independence and fortitude in lives filled with challenges, becoming comfortable members of the American middle class. Generally, the siblings adapted well to life in the New World, and surely prospered far more than they could have in Lanarkshire. As spring came to an end in 1919 and Andrew breathed his last, the Calderwoods were not yet in a position of economic security, but they had a foothold and they had each other.

He had made the leap.

Acknowledgements

This book was fifteen years in the making, and many hands helped it along. I want to first thank my "kitchen table" editors, Mike Beeler and Joshua Roth.

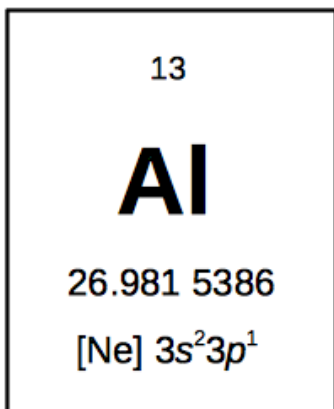
Additional thanks go to John McLeish of the East Kilbride Library for important historical materials, Bill Niven for his command of East Kilbride history, Dan Zick and Dave Richardson for metallurgical advice, my 2nd cousins Judy Weisfield and Cathy Siefkes for family history, Mark Windover for genealogy research, Philip Kaaret and Pat Slane for astrophysical consulting, Lillie Durow and Jim Mullins for chemistry advice, Chuck Devine for woodworking help, and Jeff Scheetz for grinding a new face on the mortising chisel. Important information came from the National Library of Scotland, the National Records of Scotland, and Library and Archives Canada.

The manuscript took its first, halting steps in Emily Miller's essay class at Harvard Extension School and Ellen Waterston's nonfiction writing laboratory at Central Oregon Community College. Peter Harbo and Sig Siefkes reviewed the work at various stages. Hats-off to John Moran for publishing *First You Write a Sentence*, the most useful writer's guide I've ever seen.

Finally, deep thanks to Mrs. Maguire of Bridlemile elementary school in Portland, Oregon, who made us put pencil to paper every day of second grade, and so taught her students—especially this one—how to write.

Appendix: Teaching Chemistry as History

Remember the first day of high school chemistry class? They threw the periodic table at you, and probably showed a blow-up of a particular element:



Thirteen is the atomic number of aluminum (*what's an atomic number?, you asked*). 26.9815386 is its average atomic mass (*why an average atomic mass?*), and [Ne] 3s²3p¹ is its electron configuration (*what's an electron configuration?*). From the very beginning, the students were confronted with terms that could not be satisfactorily explained until later.

Next, they beat you senseless with the rules of Significant Figures for your calculations in upcoming classwork. There then ensued a semester of unbearable tedium, punctuated by the occasional opportunity to break some glassware with the assistance of an incompetent lab partner who worked tirelessly to bring down your GPA just as the college application season drew near.

Well, maybe it wasn't that bad, but it probably wasn't good. My own enthusiasm for the chemical universe withered quickly in the classroom, and I think my experience was (and still is) far from unique. Compared with physics, the teaching of chemistry is burdened with a serious handicap. In Newtonian mechanics, a modest collection of equations governs a wide variety of

phenomena, and one learns to apply a manageable number of concepts to an ever-expanding field of applications. Chemistry, by contrast, seems plagued by an infinitude of special cases, not just in phenomena but in nomenclature. The class is a slog to assimilate all the details—a classic forest-for-the-trees situation—and this problem is not new. In his 1884 textbook *Principles of Chemistry*, Pattison Muir wrote, “The chemical student is often subjected to a shower-bath of facts...to sit as a passive bucket and be pumped into...” Various educators are working to improve this situation, and not everyone, today, is put through the grind I have described. But there remains a long way to go.

In 2011, I was reading *Lavoisier: The Next Crucial Year* by Frederic Lawrence Holmes. Antoine Lavoisier is celebrated as the first quantitative chemist, the man who ushered in the modern era of the field. His research culminated shortly before 1800, the start of a miraculous hundred years for chemistry. The scientists of that era made amazing strides, and I began to think about how their work could be adapted to contemporary education. By framing teaching in the context of the simpler world of the historical chemists, would it be possible to illustrate important chemical concepts without the overwhelming details of the “shower bath”? I eventually equipped myself with a modest lab and began to try. I not only identified teaching opportunities, I rediscovered the pleasure of wearing the White Coat, working with the tools and chemicals that had fascinated me as a kid.

By introducing students to chemistry via electron sharing, the Octet Rule, and so on, we ask them to accept phenomena that they cannot see in a practical demonstration, let alone in their own lab work. By trying some of the historical experiments for themselves, they have the opportunity to explore significant chemical questions through tangible experience without the baggage of invisible particles and forces.

At the link below you will find a modest collection of historical lab exercises. Teachers of chemistry might find interesting ideas there, and could surely come up with their own.

<http://historicalchemistry.net>

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Pilar Ruiz-Lapuente, *The Binary Progenitor of Tycho Brahe's 1572 Supernova*, Nature, October 2004

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Kuo-Chuan Pan, *Search for Surviving Companions in Type Ia Supernova Remnants*, The Astrophysical Journal, September 2014

Luigi Bedin, *Improved Hubble Space Telescope Proper Motions for Tycho-G and Other Stars in the Remnant of Tycho's Supernova 1572*, Monthly Notices of the Royal Astronomical Society, March 2014

Zhichao Xue, *Newly Determined Explosion Center of Tycho's Supernova and the Implications for Proposed Ex-Companions of the Progenitor*, The Astrophysical Journal, August 2015

Tyrone Woods, *No Hot and Luminous Progenitor for Tycho's Supernova*, Nature Astronomy, September 2017

Jun Fang, *An Explanation of the Formation of the Peculiar Periphery of Tycho's Supernova Remnant*, Monthly Notices of the Royal Astronomical Society, February 2018

Pilar Ruiz-Lapuente, *Tycho's Supernova: The View from GAIA*, The Astrophysical Journal, January 2019

2 Presented in chronological order. Nearly all of these papers have multiple authors, but I have listed only the "lead" author.

A Chemistry Reading List

Oliver Sacks, *Uncle Tungsten*

Delightful recollections of "A chemical boyhood" by the acclaimed neurologist. Can you believe that this precocious kid was making his own photographic film?

Primo Levi, *The Periodic Table*

Short stories, both personal and chemical, set largely in and around the years of the Second World War. The Italian chemist survived internment at Auschwitz and went on to become a major writer. An informal poll in 2006 declared this work to be the best science book ever written.

Peter Atkins, *The Periodic Kingdom and Reactions*

Atkins, a British chemist, is a longtime expositor of chemistry. *The Periodic Kingdom* is his classic book on the Periodic Table, while *Reactions* is a recent, nicely illustrated exploration of, well, reactions.

Michael Faraday, *The Chemical History of a Candle*

We are fortunate that a transcription of Faraday's lecture series was made. It is available from multiple publishers, but the version by the Chicago Review Press includes an appendix of home experiments.

Cathy Cobb and Monty Fetterolf, *The Joy of Chemistry*

An enjoyable romp through basic chemistry, in both the armchair and the garage lab.

Robert Brent, *The Golden Book of Chemistry Experiments*

A Sputnik-era book that encouraged kids to become interested in science (I had copy). Some of the activities were on the hazardous side, and the book disappeared from circulation. The copyright wasn't renewed, and has now expired. A digital scan can be found at thoughtco.com. Lots of experiments and marvelous 1960s-style illustrations.

Index

Color Plates

The Chemist, then and now



Christmas, 1968



Christmas, 2018

PHIXME CHEMIST PICTURES



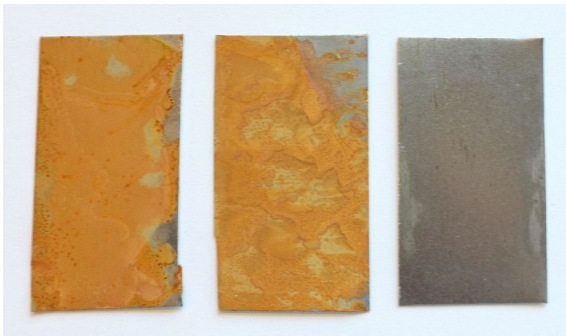
PHIXME Try-plane and smoothing plane (2planes.jpg)



PHIXME "Family portrait" (family.jpg)



PHIXME Door built with Andrew's tools (rod on left) (door.jpg)



PHIXME Steel corrosion. L-R: 24 hours in tap water, 12 hours in salt water, and 24 hours in deoxygenated water. (corrosion.jpg)