

Iron and Steel—Properties and Applications

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Abstract:

Many students are unfamiliar with the specifics related to the structure, properties and compositions of steels in common use. This module provides an introduction to iron and steel, and discusses relative strength of products, magnetic properties, crystal structure and introduces stainless steels and other alloy steels. Students learn about iron and steel through discussions, demonstrations and suggested optional activities. Cost is also introduced and related to the increased cost of processing stronger and stronger alloys. Designed for up to one class period, the unit may be adapted for any grade level between 10th and introductory college classes. No laboratory is needed and optional activities investigate objects in the classroom as well as objects at home, if desired.

Module Objective:

The objective of this module is to introduce iron and steel to the students through discussions and demonstrations of magnetism, strength, composition and crystal structure. Students also learn about relative costs and the relationship of material properties of different steels to one-another and to commonly used objects.

Student Learning Objectives: Students will be able to--

- differentiate between different steel objects and their properties and cost
- discuss the effects of carbon content on steel properties
- show the differences in magnetic properties of different materials
- demonstrate the differences in structure of different steels
- define ferritic and austenitic steels

MatEd Core Competencies Covered:

- 2.C Apply laboratory skills
- 7.A Identify the general nature of metals
- 8.C Perform visual and non-destructive testing methods for solids
- 9.A Define and describe constituents, properties and processing of steels
- 16.A Explain the effects of processing and manufacturing variations on material properties

Key Words: Iron, Steel, Magnetism, Structure, Properties

Type of Module: Demonstration, discussion, calculations, optional activities

Time Required: One to two class periods (depends on options chosen) plus calculations

Pre-requisite Knowledge: Some understanding of graphs desired

Target Grade Levels: Advanced High School, College Undergraduate

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Equipment and Supplies Needed:

Means of showing figures (given below)

Sample metal products from a shop, home or hardware store such as:

- Scissors
- Hammer
- Saw
- Chisel
- Chain
- Rebar
- Nails (steel and, if available, aluminum)
- Aluminum (products or foil)
- Copper or brass implement
- Tableware (best to have some cheap and some high quality utensils for comparison)
- Stainless steel objects, as available (can be the sink in the classroom and the tableware)
- Cast iron implement (skillet or such)

Large magnet for classroom demonstration (visible to the class)

Small magnets for student use (optional)

Magnets available from hobby, hardware or Discover stores; also available from Edmonds Scientific (see references)

Curriculum Overview and Notes for Instructor:

Iron and steel are available in many grades, strengths and conditions. This module provides only a start to understanding these systems.

Steel is made up of iron plus small amounts of carbon. Specialty steels also contain other alloying elements but all steels contain carbon since in the production process, it is very difficult to remove carbon, which is a small atom that exists in the interstitial spaces between iron atoms in the structure. The basic room temperature structure of iron and steel is called "Ferrite" or alpha-iron, and has a body centered cubic (BCC) crystal structure. Ferrite can dissolve up to .0025% carbon (by weight—engineers always use weight not atom %); any added carbon present precipitates out as iron carbide, which becomes part of the microstructure and increases strength. Above 912C (1674F) Iron transforms to a face centered cubic (FCC) structure called Austenite or gamma iron, which can dissolve much more carbon—up to 2%. The transformation from Austenite to Ferrite provides the basis for steel heat treatment, covered in another module. Structure and composition reference web sites are given in the reference list.

One easy and excellent test to differentiate between Ferrite and Austenite is through their magnetic properties. Ferrite below 770C (1418F) is ferromagnetic. Above this temperature, called the Curie temperature, it becomes paramagnetic and loses its ferromagnetic properties. Thus a magnet can identify any iron produce that consists of Ferrite. This includes most household items made of iron. Items made from other elements are not ferromagnetic with the exception of cobalt and nickel (with are too expensive for household items) and a few compounds (reference the Wikipedia discussion on Ferromagnetism on the web).

Stainless steels are a special case of steel alloys, containing chromium (Cr), which reduces corrosion. Nickel (Ni) is added to transform the material to the FCC austenitic structure, which further increases corrosion resistance. Ordinary stainless steels (with no Ni) are used for a variety of industrial applications, while austenitic stainless is used in more critical applications. Tableware is a good example of the two types of stainless steel applications, as high-class tableware is generally Austenitic (not ferromagnetic) while cheaper stainless tableware will be ferritic and ferromagnetic.

This module includes examples, demonstrations and optional experiments for the students to demonstrate these concepts. Also included are some optional mathematical calculations that require some 3-dimensional visualization, which may be appropriate for more advanced students. Depending on the level of the class, parts or all of these exercises can be used to ensure that students develop basic knowledge of steels and their properties along with some curiosity to learn more.

Module Procedure:

1. Class discussion—What is steel? How are iron and steel used?
 - a. Have the students discuss steel—what do they know about it? Can they distinguish it from aluminum and other metals?
 - b. What is the difference between iron and steel?

Instructor note: You may have to give them the answer that steel consists of iron plus small amounts of carbon
 - c. Show some examples of steel products—here are some suggestions:
Chain, scissors, saw blade, hammer, steel cable

2. Use a magnet and show that the items in 1c are magnetic
 - a. Ask the students what they know about magnetism

Instructor Note: At room temperature, only iron, cobalt and nickel and some of their alloys (such as steel) are magnetic, so this is a good way to differentiate between steel and other metals. However, note that alloy steels may not be magnetic; the best example is the austenitic grade of stainless steel (see #8 below).
 - b. Show a sample set of metal products. Demonstrate that magnets are attracted to the steel products but not to other materials including other metals such as Aluminum.

3. Show the students figure 1 on Types of Steel—discuss these points:
 - a. Where do their examples (from the classroom or from home) fit into the table?
 - b. Why are these carbon contents different? What are the differences in properties between these products? Have a general discuss then go to item 4, which will provide the answer.

4. Show the students figure 2 on comparative strength of steel products
 - a. Discuss the available products and where they go on the graph

Instructor note: You may have to introduce graphing here, depending on the level of the students.
 - b. Ask the students how they define strength of an object. (Dictionary Definition: The capacity of an object to withstand great force or pressure). Engineers use strength as force divided by cross sectional area.
 - c. Show the students the BCC crystal structure. The steel we have looked at is called "plain carbon steel" as it contains only iron and small amounts of carbon. These materials have a crystal structure called Body Centered Cubic. Carbon slightly distorts this structure—does this help in explaining the strength values shown in figure? Additional carbon precipitates out as iron carbide, further strengthening the material.

5. [OPTIONAL] Ask the students if they expect materials with higher carbon contents to cost more. Point out that one part of cost is the cost to make a product—and that a stronger product will be harder to form, thus taking

more energy to make it. Assign a homework problem to find costs of different types of steel.

6. Show the students both BCC and FCC crystal structure :
 - a. Provide the following background for plain carbon steels:
 - BCC exists at room temperature, so the products discussed above are BCC, also called alpha iron or "Ferrite." Ferrite is magnetic up to 770C (1418F)
 - FCC exists above 912C (1674F). FCC iron is also called gamma iron or "Austenite" after the person who first identified it, Sir William Roberts-Austen. Austenite is NOT magnetic.
 - *Note: Austenitic transformations are the subject of a separate lesson on heat treatment of steels—this subject should not be introduced here as it may complicate the lesson.*
 - b. Like most materials, iron expands as it is heated. It expands even more when it transforms from BCC to FCC because FCC is a more dense structure (see calculation BELOW).
 - Show the students the simple demonstration of this, called the "iron wire experiment." One source for this experiment is shown in the reference list.
 - c. [OPTIONAL CALCULATION] BCC iron at 912C has a lattice constant (length of the side of the BCC cell) of 0.2906nm. FCC iron at the same temperature has a lattice constant of 0.3615 nm.
 - Using the FCC and BCC structure geometries, calculate the percentage change when BCC changes to FCC.
 - *Note: the details of, and the solution to this problem are straightforward but require an understanding of 3-D geometry. Sample solution attached.*
 - d. At room temperature, the lattice constant (the side of the BCC cell) is 0.2870nm. At 770C, where BCC iron loses its magnetism, the lattice constant is 0.2898nm. It has been shown that the principal reason that iron loses its magnetism at this point is the that iron atoms become too far apart to properly interact for the proper ferromagnetic interaction.
 - Show the students the simple demonstration showing that an iron wire will lose its magnetism at this temperature. One source for this experiment is given as a reference.
 - e. [OPTIONAL CALCULATION] Calculate the closest approach distance between iron atoms at room temperature and at 770C.
 - *Note: the details of, and the solution to this problem are straightforward but require analysis of the 3-D geometry of the structure. Sample solution attached.*
7. There are lots of other types of steel, called alloy steel:
 - a. Alloying additions strengthen steels. Typical examples include manganese, nickel, molybdenum, chromium and vanadium. These elements are added depending on the properties and strength that

- result. Show these elements to the class on a periodic chart. Where are they relative to iron? If desired, refer the students to the listing of "SAE steel grades" found on Wikipedia.
- b. Some of these elements (principally nickel) cause iron to be FCC at room temperature. Ask the students how they could detect if iron is FCC at room temperature (Use a magnet).
8. Stainless steel is a good example of an alloy steel. There are several types of stainless steel—here we deal only with the simplest:
- a. Ferritic stainless steels are BCC and contain 17% or more chromium, which causes them to be corrosion resistant (but never corrosion proof). Ferritic stainless is used for industrial applications and less expensive implements—examples include stainless steel sinks and inexpensive tableware. Show examples and have the students test with a magnet.
 - Demonstrate that ferritic stainless is not corrosion proof by wetting a stainless surface (such as your lab sink) and placing a glass or other object on it. Wait for a few hours and "rust" (iron oxide) will form under the object. This happens generally in a covered location on stainless where there is a lack of oxygen.
 - b. Austenitic stainless steels are FCC and contain both chromium (for corrosion resistance) and nickel (for added corrosion resistance and to transform it to FCC). Examples are high-end tableware and high quality industrial applications. Common types of Austenitic stainless are:
 - Type 304 with 18% Cr, 8% Ni, .08% C.
 - Type 316 with 17 - 25% Cr, 8 - 20% Ni, .08% C plus other alloying additions such as Mo to improve corrosion resistance. Most common is called 18/8 for 18% Cr and 8% Ni. This type of stainless is used in marine environments, food handling and pharmaceutical product manufacture; 316L, with lower carbon content (less than .03%) is used in surgery and other applications.
 - Have the students find applications for different types of stainless steel—there is information on the web or in appropriate libraries.
 - Discuss the question of cost again—these alloying elements not only make the material stronger in most cases, but these alloying elements are also expensive. Students can search for costs of these materials on the internet.

Supporting Handouts and Materials:

Figure 1, types of steels

Figure 2, strength of steel as a function of carbon content (with sample products)
BCC and FCC crystal structure drawings
Solution to calculation problems

References

1. The following web sites can be used for reference for the instructor and for the students:
 - a. Types of steel:
<http://resources.schoolscience.co.uk/corus/14-16/steel/msch3pg1.html>
 - b. SAE Steel grades: http://en.wikipedia.org/wiki/AISI_steel_grades
 - c. Iron wire experiment:
http://www.sfu.ca/physics/ugrad/courses/teaching_resources/demonindex/thermal/th4c/fewire.html
 - d. Magnetism of iron experiment:
[http://naples.cc.sunysb.edu/CAS/pdemos.nsf/By+Course+Number/\[1.+Electrostatics+And+Magnetostatics\]7.+Magnetic+Materials+\[7-12Curie+Point+Of+Iron](http://naples.cc.sunysb.edu/CAS/pdemos.nsf/By+Course+Number/[1.+Electrostatics+And+Magnetostatics]7.+Magnetic+Materials+[7-12Curie+Point+Of+Iron)
 - e. Background on ferromagnetism:
<http://en.wikipedia.org/wiki/Ferromagnetic>
 - f. What is Stainless Steel? http://en.wikipedia.org/wiki/Stainless_steel
 - g. Stainless Steel:
<http://chemistry.about.com/cs/metalsandalloys/a/aa071201a.htm>
 - h. Lattice constant of Iron:
http://www.jstage.jst.go.jp/article/isijinternational/45/12/45_1789/article
2. Sources of magnets for demonstration and for student use include hobby shops, hardware stores, Discover stores, and science suppliers. One easy source is Edmonds Scientific:
<http://scientificsonline.com/category.asp?c=421188&bhcd2=1221950363>

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Evaluation Packet

Student evaluation questions (discussion or quiz):

1. Explain why some steel is stronger than others
2. What causes iron to lose its magnetism at 723C?
3. What alloying elements are added to make steel corrosion resistant?
4. Discuss the differences between different steel objects and their properties and cost

5. Explain the effects of carbon content on steel properties and cost
6. Explain the differences in magnetic properties of different materials
7. Define ferritic and austenitic steels

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the demonstration (and classroom exercise if used) work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material on steels sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the exercise generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the module clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned?