Chapter 1

Metals

Elements that transmit electricity well, even at low temperatures, are called *metals*. Many metals are likely familiar to you, such as aluminum, iron, copper, tin, gold, silver, and platinum. Aluminum and iron are particularly common; together they make up about 14% of the earth's crust.

An *alloy* is a mixture of elements that includes at least one metal. Brass, for example, is an alloy of copper and zinc. Bronze is an alloy of copper and tin.

1.1 Steel

One of the most common alloys is steel, which is an alloy of iron and carbon. In pure iron, the molecules slip past each other easily, so pure iron is relatively soft and easily deformed. The carbon in steel prevents that slipping, which is why steel is much, much harder than iron.

How much carbon does steel have? If you have less than 0.002% by weight, you end up with something very much like pure iron. As you increase the carbon, it gets harder and harder. Once it gets above about 2%, the result is very brittle.

If you add about 11% chromium to steel, you get *stainless steel*, which resists rusting.

Exercise 1 Tensile Strength

Working Space

The tensile strength of steel is usually between 400 MPa and 1200 MPa. A Mega Pascal (MPa) is the strength necessary to hold 1,000,000 newtons of force with a cable that has a 1 square meter cross section. Or, equivalently, to hold 1 newton of force with a cable that has a 1 square millimeter cross section.

If you have are buying a round cable that has a tensile strength of 700 Mpa and must hold a 100 kg man aloft, what is the diameter of the smallest cable you can use?

Answer on Page 5

Here are some approximate tensile strengths of other materials:

Material	Tensile strength (MPa)
Iron	3
Concrete	4
Rubber	16
Glass	33
Wood	40
Nylon	100
Human hair	200
Aluminum	300
Steel	700
Spider webs	1000
Carbon fiber	4000

1.2 What metal for what task?

Copper is often used for electrical wires in your house and appliances. This is because it is very efficient at moving electricity (very little power is lost as heat). It is also very good

a transmitting heat, so you will often see copper pots and pans.

Aluminum is less dense than copper, and is still a relatively good conductor of electricity. This combination of lighter weight and conductivity is why the overhead wires in a power system are often made of aluminum.

Aluminum is not as strong as steel, but considerably lighter. It is often used structurally where weight is a concern, such as in skyscrapers, cars, airplanes, and ships.

Titanium is about as strong as steel, but it weights about half as much. Titanium is very difficult to work with, so it is used in places where weight and strength are very important and cost is not, such as in airplanes and bicycles. FIXME: We mention airplanes in both examples. Maybe we should clarify the role each one plays?

(Carbon fiber, which is light, strong, and very easy to work with, is replacing aluminum and titanium in many applications. 20 years ago, many expensive bicycles were made of titanium. These days the vast majority are made with carbon fiber.)

Zinc and tin are very resistant to corrosion, so they are often used as a coating to prevent steel from rusting. They are also used in many alloys for the same reason. In the United States, the penny is 97.5% zinc and only 2.5% copper.

Appendix A

Answers to Exercises

Answer to Exercise 1 (on page 2)

On earth, holding a 100 kg man aloft requires 980 Newtons of force.

$980/700 = 1.4$, so you need a cable with a cross-section area of 1.4 square millimeters.

$$\pi r^2 = 1.4$$

$r = \sqrt{1.4/\pi} \approx .67$ millimeters. This means the cable would have to have a diameter of at least 1.34 millimeters.