Contents

Chapter 1

Fertilizer

FIXME First, Allison has learned she does not need a colon after FM

Here are some thoughts on expanding the introduction to the Fertilizer Chapter. This might be a good moment to discuss the multidisciplinary nature of Kontinua. In a regular science class I'm guessing you wouldn't get electricity and Fertilizer in the same textbook. Why is there a chapter on Fertilizer here? Are you introducing us to the major ways science has given us more power and allowed population to grow? Can we discuss your thoughts on why problem solvers need a basic understanding of Fertilizer and I'll write up a new introduction to this chapter based on the discussion?

What do you think about adding a conclusion that talks about the connection between fertilizer (nitrogen), dynamite and the origin of the Nobel peace prize? I know you don't want too much history and philosophy but this seems like a great moment to add a little narrative spice.

Can we work POTATOES into this chapter!?!

Chapter text starts here:

One of the biggest problems humans face is: how can we get enough food to feed everyone? In 1950, there were 2.5 billion people on the planet, and about 65% were malnourished. In 2019, there were 7.7 billion people on the planet, and only 15% are malnourished. How did crop yields increase so much? There were several factors: better crop varieties, reliable irrigation, increased mechanization, and affordable fertilizers.

When a plant grows, it takes molecules out of the soil and uses them to build proteins. It primarily needs the elements nitrogen (N), phosphorus (P), and potassium (K).

When you buy a bag of fertilizer at the store, it typically has three numbers on the front. For example, you might buy a bag of "24-22-4". This means that 24% of the mass of the bag is nitrogen, 22% is phosphorus, and 4% is potassium.

Potassium comes as potassium carbonate (K_2CO_3), potassium chloride (KCl), potassium sulfate (K_2SO_4), and potassium nitrate (KNO_3). Any blend of these chemicals is known as "potash". Potash is dug up out of mines.

Phosphorus is also mined, but is refined into phosphoric acid (H_3PO_4) before it is put into fertilizer.

Nitrogen is an especially interesting case for 2 reasons:

- Worldwide, farmers apply more nitrogen to their soil than potassium or phosphorous combined.
- 78% of the air we breathe is nitrogen in the form of N_2, but neither plants nor animals can utilize nitrogen in that form.

1.1 The Nitrogen Cycle

Converting the N_2 in the air into a form that a plant can use is known as *nitrogen fixation*. For billions of years, there were only two ways that nitrogen fixation occurred on earth:

- The energy from lightning causes N_2 and H_2O to reconfigure as ammonia (NH_3) and nitrate (NO_3). This accounts for about 10% of all naturally occurring nitrogen fixation.
- Cyanobacteria are responsible for the rest. They convert N_2 into ammonia.

Let's say that you are eating soybeans. There is a cyanobacteria called *rhizobia* that has a symbiotic relationship with soybean plants. Rhizobia fixes nitrogen for the soybean plant. The soybean plant performs photosynthesis, then gives sugars to the rhizobia.

The proteins in the soybeans contain nitrogen from the rhizobia. When you eat them, you use some of the nitrogen to build new proteins. You probably don't use all the nitrogen, so your cells release ammonia into your blood.

Ammonia likes to react with things, so your liver combines the ammonia with carbon dioxide to make urea $(CO(NH_2)_2)$. Your kidneys take the urea out of your blood and mix it with a bunch of water and salts in your bladder. When you urinate, the urea leaves your body.

If you urinate on the ground, the nearby plants can take the nitrogen out of the urea.

When you die, the nitrogen in your proteins will return to the soil as ammonia and nitrate.

For centuries, farms got their nitrogen from urine, feces, and rotting organic material. There were two challenges with this:

- Human pathogens had to be kept away from human food.
- There was simply not enough to support 7.7 billion people.

This meant we had to figure out how to do nitrogen fixation at an industrial level.

1.2 The Haber-Bosch Process

During World War I, two German scientists, Fritz Haber and Carl Bosch, figured out how to make ammonia from N_2 and H_2 using high temperatures and pressures. This is how nearly all nitrogen fertilizer is created today.

Where do we get the H_2? From methane (CH_4) in natural gas. Today, 3-5% of the world's natural gas production is consumed in the Haber-Bosch process.

The ammonia is converted into ammonium nitrate (NH_4NO_3) or urea before it is shipped to farms.

1.3 Other nutrients

Healthy plants require several other elements that are sometimes applied as fertilizer: calcium, magnesium, and sulfur.

Finally, tiny amounts of copper, iron, manganese, molybdenum, zinc, and boron are sometimes needed.

Chapter 2

Concrete

To make concrete, you mix cement with water and an aggregate (sand or rock). The cement is usually only about 10 to 15 percent of the mixture. The cement reacts with the water, and the resulting solid binds the aggregate together. In 2019, the world consumed 4.5 billion tons of cement.

Concrete is hard and durable. The mortar between the pyramids at Giza is concrete — it is now 5000 years old. Today, we use concrete to build many structures including buildings, bridges, airport runways, and dams.

There are many kinds of cement, but the most common is Portland cement. It is made by heating limestone (calcium carbonate) with clay (for silicon) in a kiln. Two things come out of the kiln: Carbon dioxide and a hard substance called "clinker". The clinker is ground up with some gypsum before it is sent to market.

The carbon dioxide is released into the atmosphere. Cement manufacture is responsible for about 8% of the world's CO_2 emissions; it is a major contributor to climate change.

Especially hard concrete, like that used in a nuclear power plant, can support 3,000 kg per centimeter without being crushed. However, if you pull on two ends of a piece of concrete, it comes apart relatively easily. We say that concrete can handle a lot of *compressive stress*, but not much *tensile* stress.

2.1 Steel reinforced concrete

Many places where we use concrete (like in a bridge), we need both compressive and tensile stress. Often, the top of a beam is undergoing compression and the bottom of the beam is undergoing tension.

FIXME Picture here

Steel has tremendous tensile strength, but not as much compressive strength as concrete. To get both tensile *and* compressive strength, we often bury steel bars or cables inside the concrete. This is known as *steel-reinforced concrete*. The concrete generally does a very good job protecting the steel, which keeps it from rusting.

You may have heard of *rebar* before. That is just short for "reinforcing bar". Typically, rebar has bumps and ridges that keep the bar and the concrete from moving independently.

2.2 Recycling concrete

Many concrete structures only last about 100 years. When they are demolished, the concrete can be reused as aggregate in other projects. Often, the concrete bits are mixed with cement and made into concrete once more.

If the concrete to be reused is reinforced with steel, the steel has to be removed and recycled separately. The concrete is then crushed into small pieces.

Chapter 3

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.

3.1 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

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?

Working Space

Answer on Page 21

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

3.2 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?

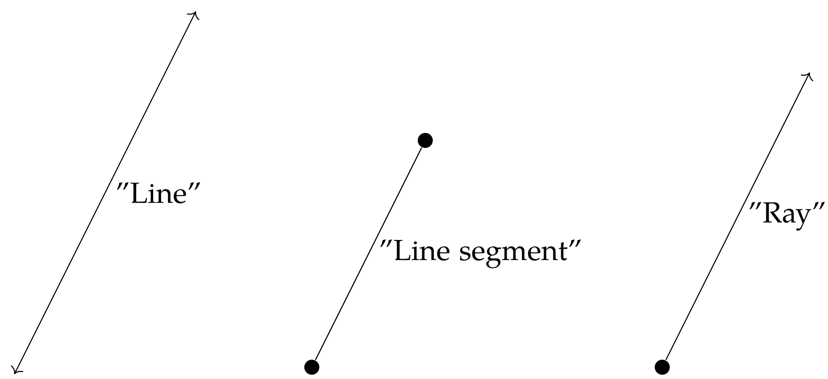
(Carbon fiber, which is light, strong, and very easy to work with, is replacing aluminum and titanium in many applications. 20 years ago, many expensive bicycles were made of titanium. These days the vast majority are made with carbon fiber.)

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.

Chapter 4

Angles

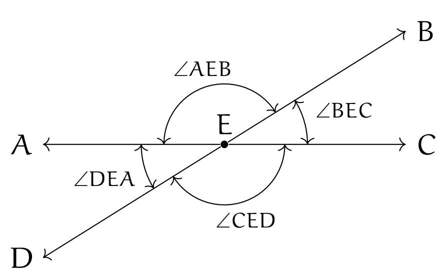
In the following recommend videos, the narrator talks about lines, line segments, and rays. When mathematicians talk about *lines*, they mean a straight line that goes forever in two directions. If you pick any two points on that line, the space between them is a *line segment*. If you take any line, pick a point on it, and discard all the points on one side of the point, that is a *ray*. All three have no width.



Watch the following videos from Khan Academy:

- Introduction to angles: `https://youtu.be/H-de6Tkxej8`
- Measuring angles in degrees: `https://youtu.be/92aLiyeQj0w`

When two lines cross, they form four angles:



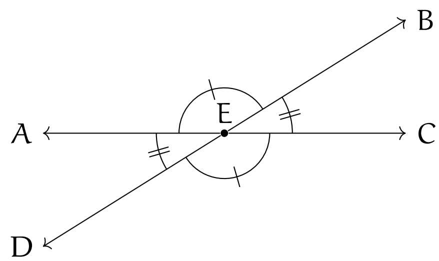
What do we know about those angles?

- The sum of any two adjacent angles adds to be $180°$. So, for example, $m\angle AEB +$

$m\angle BEC = 180°$. We use the phrase "adds to be 180°" so often that we have a special word for it: *supplementary*.

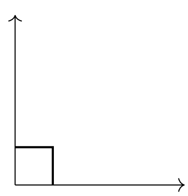
- The sum of all four angles is 360°.
- Angles opposite each other are equal. So, for example, $m\angle AEB = m\angle CED$.

In a diagram, to indicate that two angles are equal we often put hash marks in the angle:

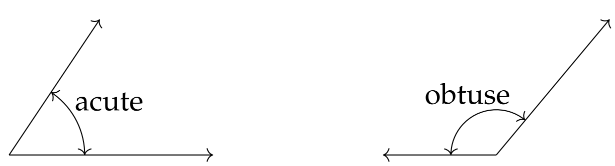


Here, the two angles with a single hash mark are equal, and the two angles with double hash marks are equal.

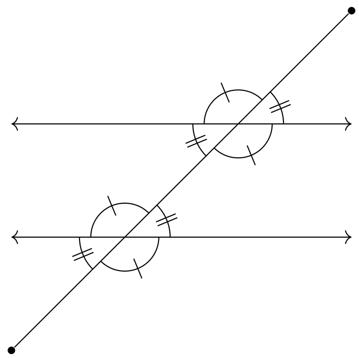
When two lines are perpendicular, the angle between them is 90°, and we say they meet at a *right angle*. When drawing diagrams, we indicate right angles with an elbow:



When an angle is less than 90°, it is said to be *acute*. When an angle is more than 90°, it is said to be *obtuse*.



If two lines are parallel, line segments that intersect both lines form the same angles with each line:



4.1 Radians

As you've seen above, angles can be measured in degrees. Just like you can measure length in more than one unit (inches, meters, etc.), there is more than one unit to measure angles in. Angles can also be measured in *radians*. Radians are unitless (that is, you don't have to put a letter after the number) and there are π radians across a straight line. This means $180°$ is the same as π radians.

Example: An angle is measured to be $\frac{\pi}{2}$ radians. What is the angle in degrees?

Solution: Since we know that π radians is the same as $180°$, we can set up the unit conversion:

$$\frac{\pi}{2} \cdot \frac{180°}{\pi} = 90^o$$

Therefore, a $\frac{\pi}{2}$ angle is $90°$.

Exercise 2

Convert the following angles from degrees to radians, or from radians to degrees.

1. $360°$
2. $\frac{\pi}{3}$
3. $225°$
4. $\frac{3\pi}{4}$
5. $30°$
6. $45°$

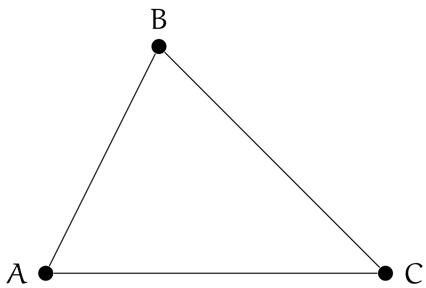
Working Space

Answer on Page 21

Chapter 5

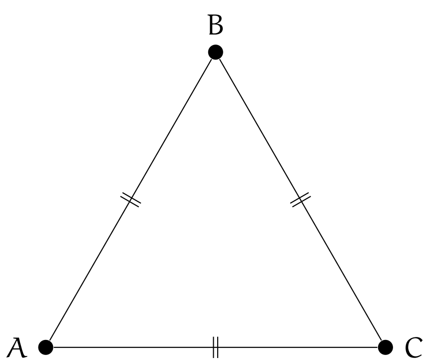
Introduction to Triangles

Connecting any three points with three line segments will get you a triangle. Here is the triangle ABC, which was created by connecting three points A, B, and C:

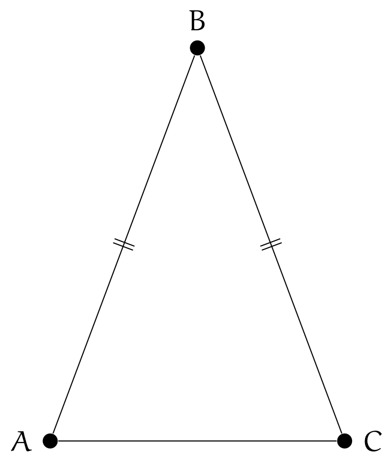


5.1 Equilateral and Isosceles Triangles

We talk a great deal about the length of the sides of triangles. If all three sides of the triangle are the same length, we say it is an *equilateral triangle*:

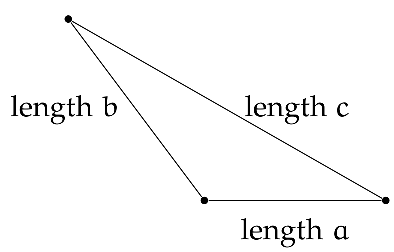


If only two sides of the triangle are the same length, we say it is an *isosceles triangle*:



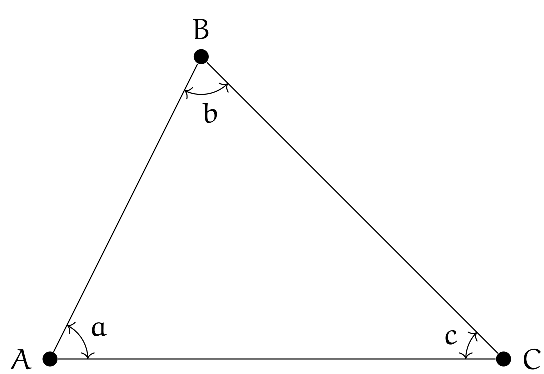
The shortest distance between two points is always the straight line between them. This means you can be certain that the length of one side will *always* be less than the sum of the lengths of the remaining two sides. This is known as the *triangle inequality*.

For example, in this diagram, c must be less than $a + b$.

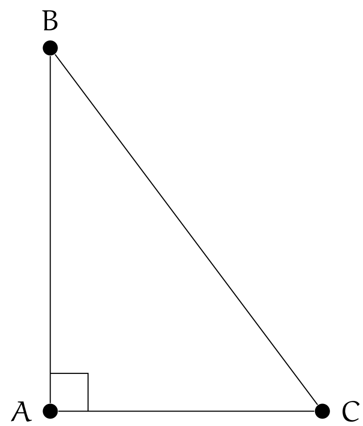


5.2 Interior Angles of a Triangle

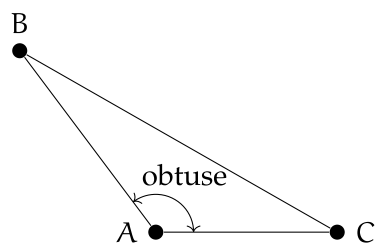
We also talk a lot about the interior angles of a triangle:



A triangle where one of the interior angles is a right angle is said to be a *right triangle*:



If a triangle has an obtuse interior angle, it is said to be an *obtuse triangle*:



If all three interior angles of a triangle are less than 90°, it is said to be an *acute triangle*.

The measures of the interior angles of a triangle always add up to 180°. For example, if we know that a triangle has interior angles of 37° and 56°, we know that the third interior angle is 87°.

Exercise 3 Missing Angle

One interior angle of a triangle is 92°. The second angle is 42°. What is the measure of the third interior angle?

Working Space

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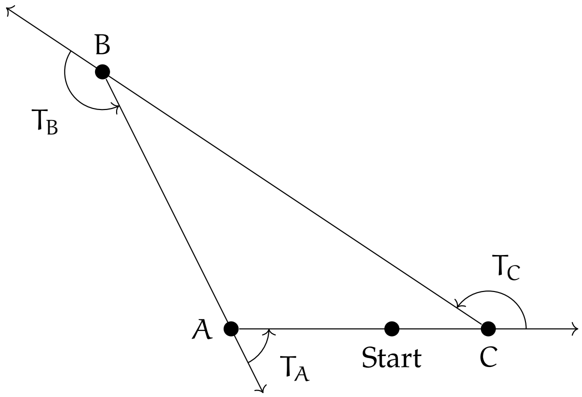
How can you know that the sum of the interior angles is 180°? Imagine that you started on the edge of a triangle and walked all the way around to where you started. (going counter-clockwise.) You would turn three times to the left:



After these three turns, you would be facing the same direction that you started in. Thus, $T_A + T_B + T_C = 360°$. The measures of the interior angles are a, b, and c. Notice that a and T_A are supplementary. So we know that:

- $T_A = 180 - a$
- $T_B = 180 - b$
- $T_C = 180 - c$

So we can rewrite the equation above as

$$(180 - a) + (180 - b) + (180 - c) = 360°$$

Which is equivalent to

$$a + b + c = 360°$$

Exercise 4 Interior Angles of a Quadrilateral

Any four-sided polygon is a *quadrilateral*. Using the same "walk around the edge" logic, what is the sum of the interior angles of any quadrilateral?

Working Space

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Appendix A

Answers to Exercises

Answer to Exercise 1 (on page 10)

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.

Answer to Exercise 2 (on page 16)

1. 2π
2. $60°$
3. $\frac{5\pi}{4}$
4. $135°$
5. $\frac{\pi}{6}$
6. $\frac{\pi}{4}$

Answer to Exercise 3 (on page 19)

$180° - (92° + 42°) = 46°$

Answer to Exercise 4 (on page 20)

$360°$

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