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Chapter 1

Chemical Reactions

1.1 Chemical Reactions

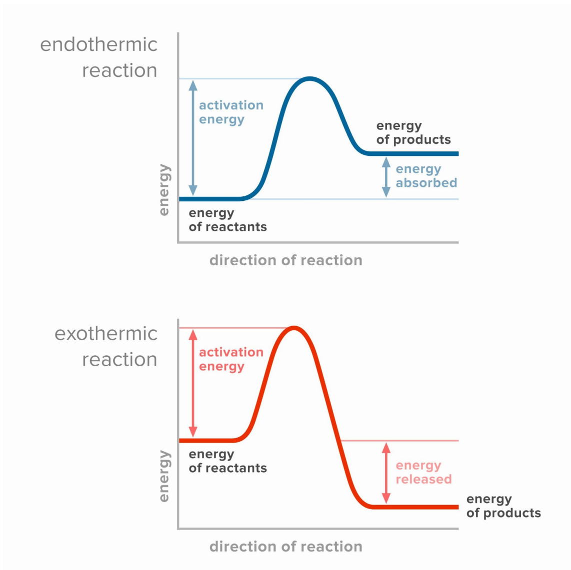


Figure 1.1

Sometimes two hydrogen atoms form a molecule (H_2). Sometimes two oxygen atoms form a molecule (O_2). If you mix these together and light a match, they will rearrange themselves into water molecules. This is called a *chemical reaction*. In any chemical reaction, the atoms are rearranged into new molecules.

Some chemical reactions (like the burning of hydrogen gas described above) are *exothermic* — that is, they give off energy. Burning hydrogen gas happens quickly and gives off a lot of energy. If you have enough, it will make quite an explosion!

Other chemical reactions are *endothermic* — they consume energy. Photosynthesis, the process by which plants consume energy from the sun to make sugar from CO_2 and H_2O requires an endothermic chemical reaction.

Examine the diagrams in figure 1.1. The x-axis represents time - time passes as wemove from left to right across the diagram. At the far left, the energy of the reactants (the ingredients that go into the reaction) is shown. At the far right, the energy of the products (what is made in the chemical reaction) is shown. The red diagrams shows an exothermic reaction: the products (what is made) have less energy than the reactants (the "ingredients" that start the reaction). Since energy is never created or destroyed, where did the energy go? It is released as heat. So, exothermic reactions release heat.

Now, look at the endothermic reaction diagram (the blue one). Based on the relative energies of the reactants and products, do you expect and endothermic reaction to release or absorb heat? Absorb! Since the products have more energy, they must have absorbed energy, in the form of heat, from the surroundings. What does this look and feel like in real life? If an exothermic reaction were happening in a glass beaker, you would feel warmth if you held the beaker. The heat is leaving the beaker and entering your hand, which feels warm. What about an endothermic reaction? Many students think that since an endothermic reaction absorbs heat, it must be getting hot. This is incorrect: *exothermic* reactions feel hot. If an endothermic reaction were happening in a beaker and you touched the beaker, it would feel **cold**. Why? Well, if the reaction is absorbing heat, then heat must be leaving it surroundings (your hand) and entering the reaction (this heat energy is turned into chemical energy that is stored in the new chemical bonds that are forming). So your hand feels cold.

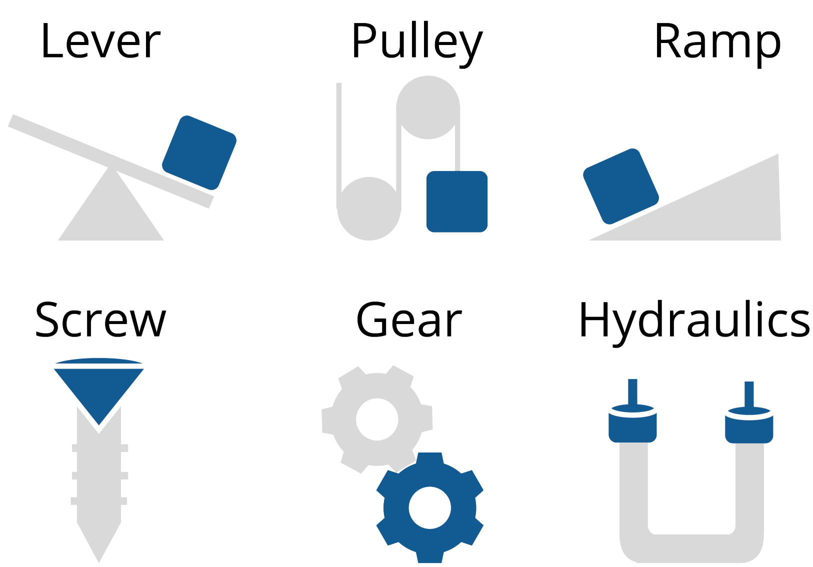
Chapter 2

Simple Machines

As mentioned earlier, physicists define work as the force applied times the distance over which it is applied. For example, if you push your car 100 meters with a force of 17 newtons, you have done 1700 joules of work.

Humans have long needed to move heavy objects, so many centuries ago, we developed simple machines to reduce the amount of force necessary to perform such tasks. These include:

- Levers
- Pulleys
- Inclined planes (ramps)
- Screws
- Gears
- Hydraulics
- Wedges



While these machines can reduce the force needed, they do not change the total amount of work that must be done. For instance, if the force is reduced by a factor of three, the distance over which the force must be applied increases by the same factor.

The term *mechanical advantage* refers to the increase in force achieved by using these machines.

2.1 Mechanical Advantage

As indicated above, mechanical advantage is the ratio between the force output by the machine and the force the user puts into the machine:

$$MA = \frac{F_{out}}{F_{in}}$$

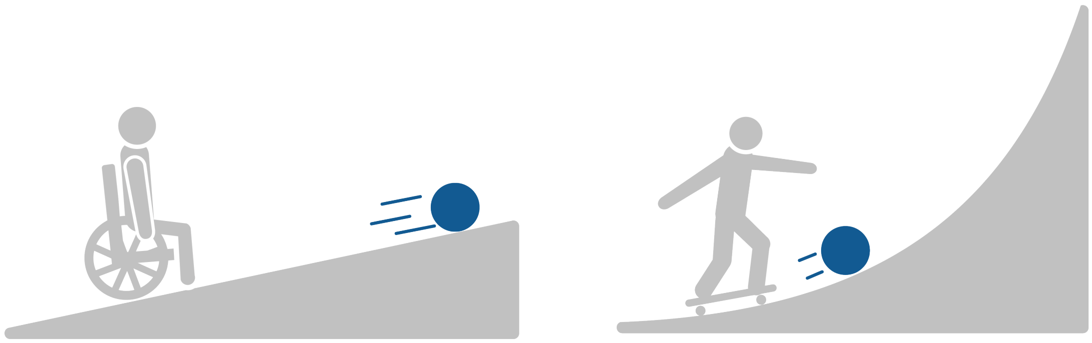
Since the input force is *applied* to the simple machine, sometimes the input force is called an applied force and abbreviated as F_a. For example, you only need to apply a relatively little force to your car's brakes in order for the hydraulic braking system to apply enough force to your tires to stop them spinning (we'll examine this further below).

2.1.1 What does it mean to work hard?

Humans use simple machines to "make work easier", but what does this mean in a physics sense? Does using a machine actually decrease the amount of work the user has to do? When we say a task is easier, we usually mean *we have to apply less force*. You might say that it is "less work" to push something up a shallow incline than up a steep incline. But does the person pushing *actually do less work* (in a physics sense), or does that work simply require a smaller force? We'll answer this question by examining the physics of incline planes below, and the results will be true for all simple machines.

2.2 Inclined Planes

Inclined planes, or ramps, allow you to roll or slide objects to a higher level. Steeper ramps require less mechanical advantage. For instance, it is much easier to roll a ball up a wheelchair ramp than a skateboard ramp.

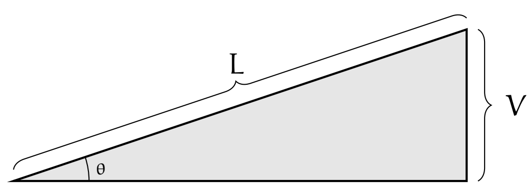


Assuming the incline has a constant steepness, the mechanical advantage is equal to the ratio of the length of the inclined plane to the height it rises.

If friction is neglected, the force required to push a weight up the inclined plane is given by:

$$F_A = \frac{V}{L} F_g$$

where F_A is the applied force, L is the length of the inclined plane, V is the vertical rise, and F_g is the gravitational force acting on the mass.



(We will discuss sine function later, but in case you're familiar with it, note that:

$$\frac{V}{L} = \sin\theta$$

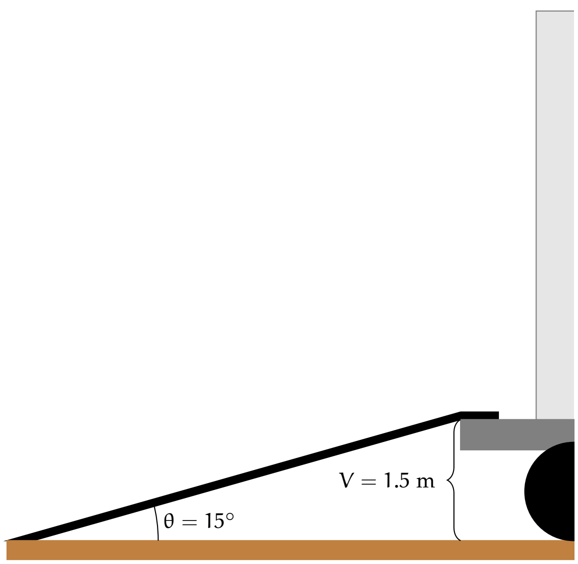
where θ is the angle between the inclined plane and the horizontal surface.)

Let's compare the force needed and work done when pushing a load up a ramp versus just lifting it vertically. Consider a family on moving day: there's a hand trolley loaded with 200 N (about 45 pounds) of boxes. If the bed of the moving truck is 1.5 m high, how much work would it take to lift the boxes straight up into the truck? What about with a ramp?

First, let's look at how much force and work is needed if you were to lift the entire 200 N load straight up into the air. You'd need to apply 200 N of force upwards for a distance of 1.5 m:

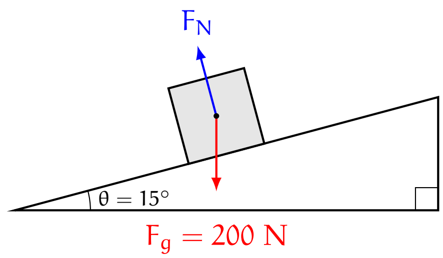
$$W = F \cdot d = (200 \text{ N})(1.5 \text{ m}) = 300 \text{ J}$$

So, without a ramp, you would have to apply 200 N and do 300 J of work. Suppose your moving truck comes with a ramp that has an incline of 15 degrees:

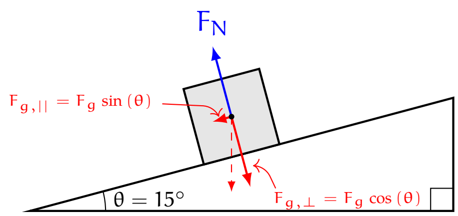


Since $\sin(\theta) = V/L$, we know that $L = V/\sin(\theta)$. You can use a calculator or search engine to find that the sine of $15° \approx 0.26$. Therefore, the length of the ramp is approximately 5.8 meters. How much force does it take to move the load of boxes up the ramp? Intuitively, we know it is less force. We can use a *free body diagram* to determine the minimum force needed to push the box up the ramp. (A free body diagram is a simplified model showing all the forces acting on an object. You'll learn to create and use your own free body diagrams in a later chapter. For now, just follow along.)

Before you push it, there are two forces acting on the loaded hand trolley: its weight (F_g) and the normal force between the trolley and the ramp (F_N):

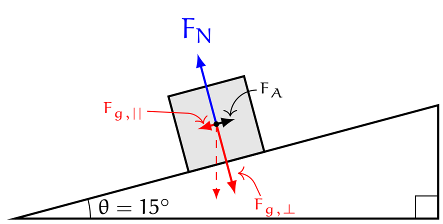


Notice that the normal force is perpendicular to the ramp! We want to know how much force it takes to push the load up the ramp, so we will "split" the weight force vector into two parts: one part parallel to the ramp ($F_{g,||}$) and one part perpendicular ($F_{g,\perp}$):



We did this by treating the weight vector as the hypotenuse of a right triangle with legs perpendicular and parallel to the ramp. You'll learn how to do this and why it works in the chapter on vectors. For now, just trust that the part of the hand trolley's weight that is perpendicular to the ramp is $F_g \cos(\theta)$ and the part that is parallel to the ramp is $F_g \sin(\theta)$.

What force do you need to overcome to push the hand trolley up the ramp? Just the part of the weight that is parallel to the ramp! You'll need to apply an equal force in the opposite direction (up the ramp) to move the hand trolley:



So, we know that you are pushing with an applied force of $F_A = F_{g,||} = F_g \sin(\theta)$. Therefore, the work you would do pushing the hand trolley up the ramp is:

$$F_A \cdot L = F_g \sin(\theta) \cdot \left(\frac{V}{\sin(\theta)}\right) = F_g \cdot V = 300 \text{ J}$$

Therefore, when using a ramp, you still perform the same amount of work! This is a key property of simple machines: *the work done doesn't change*.

So what makes it "easier" to use a ramp to lift the hand trolley? The fact that you need to apply less *force* to move the hand trolley ($F_A < F_g$). Now, let's look at the mechanical advantage of the ramp. In this case, the mechanical advantage is given by:

$$MA = \frac{F_g}{F_A}$$

Substituting for F_A, we see that:

$$MA = \frac{F_g}{F_g \sin(\theta)} = \frac{1}{\frac{V}{L}} = \frac{L}{V}$$

So for a ramp whose length is L and vertical rise is V, the mechanical advantage is equal to the length divided by the rise.

Ramps

For a ramp, the mechanical advantage is equal to $\frac{L}{V}$ and the force needed to push an object with weight W up the ramp is given by $W \cdot \frac{V}{L} = W \cdot \sin(\theta)$, where L is the length of the ramp, V is the vertical rise of the ramp, and θ is the angle the ramp forms with the (horizontal) ground.

Exercise 1 Ramp

You need to lift a barrel of oil with a mass of 136 kilograms. You can apply a force of up to 300 newtons. You need to get the barrel onto a platform that is 2 meters high. What is the shortest length of inclined plane you can use?

Working Space

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2.3 Levers

A lever pivots on a fulcrum. To decrease the necessary force, the load is placed closer to the fulcrum than where the force is applied.

Physicists also discuss the concept of *torque* created by a force. When you apply force to a lever, the torque is the product of the force you exert and the distance from the point of rotation.

Torque is typically measured in newton-meters (N·m).

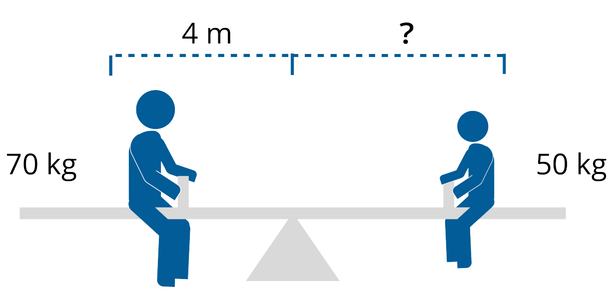
To balance two torques, the products of force and distance must be equal. Thus, assuming the forces are applied in the correct direction, the equation becomes:

$$R_L F_g = R_A F_A$$

where R_L and R_A represent the distances from the fulcrum to where the load's weight and the applied force are exerted, respectively, and F_g and F_A are the magnitudes of the forces.

Exercise 2 Lever

Paul, whose mass is 70 kilograms, sits on a see-saw 4 meters from the fulcrum. Jan, whose mass is 50 kilograms, wishes to balance the see-saw. How far should Jan sit from the fulcrum?



Working Space

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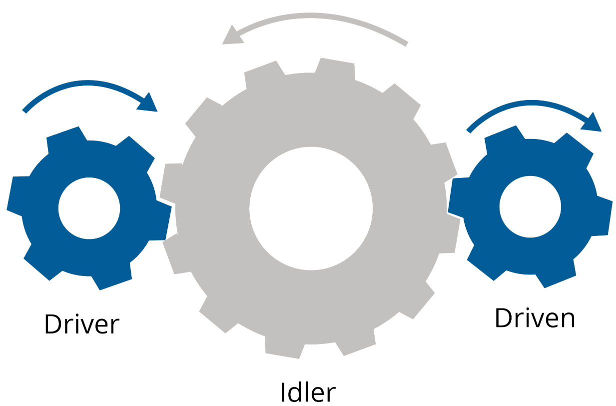
2.4 Gears

Gears have teeth that mesh with each other. When you apply torque to one gear, it transfers torque to the other. The resulting torque is increased or decreased depending on the ratio of the number of teeth on the gears.



If N_A is the number of teeth on the gear you are turning with a torque of T_A, and N_L is the number of teeth on the gear it is turning, the r esulting torque is:

$$T_L = \frac{N_A}{N_L} T_A$$

Exercise 3 Gears

In a bicycle, the goal is not always to gain mechanical advantage, but to spin the pedals slower while applying more force.

You like to pedal your bike at 70 revolutions per minute. The chainring connected to your pedals has 53 teeth. The circumference of your tire is 2.2 meters. You want to ride at 583 meters per minute.

How many teeth should the rear sprocket have?

Working Space

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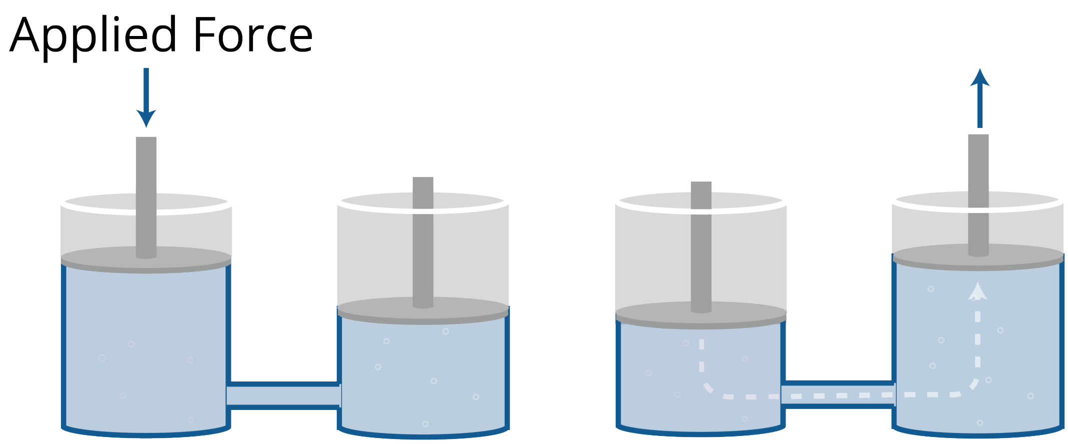
2.5 Hydraulics

In a hydraulic system, such as a car's braking system, you exert force on a piston filled with fluid. The fluid transmits this pressure into another cylinder, where it pushes yet another piston that moves the load. The pressure at each end of the hydraulic system must be the same.



Pressure is force applied to an area; it is calculated by dividing the force by the area. The pressure in the fluid is typically measured in pascals (Pa), which is equivalent to N/m^2. We will use pascals for this calculation.

To calculate the pressure you create, divide the force applied F_a by the area of the piston head A. To determine the force on the other piston, multiply the pressure by the area of the second piston.

$$P = \frac{F_{a_1}}{A_1} = \frac{F_{a_2}}{A_2}$$

Exercise 4 Hydraulics

Your car has disc brakes. When you apply 2,500,000 pascals of pressure to the brake fluid, the car stops quickly. As the car designer, you want this to require only 12 newtons of force from the driver's foot.

What should the radius of the master cylinder (the piston the driver pushes) be?

Working Space

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2.6 Pulleys

2.7 Wedges

Chapter 3

Buoyancy

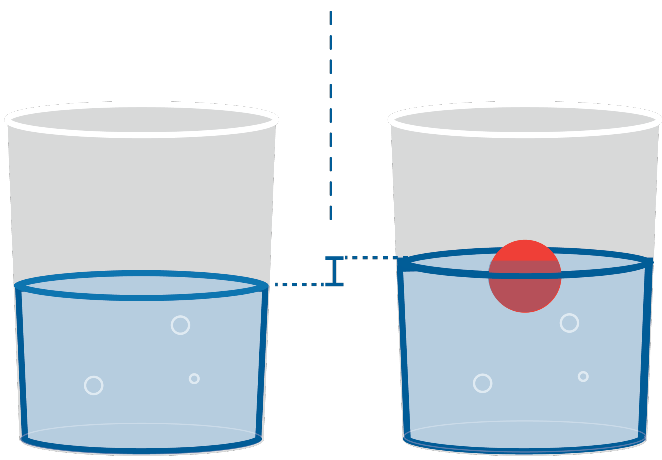
The word buoyancy probably brings to mind images of floating in water. Before we dive in, let's zoom out for a better understanding of everything buoyancy entails. You may be thinking: I want to be a computer programmer, why do I need to know about buoyancy? You might be surprised! This topic is much bigger than it seems at first glance.

Buoyancy concerns the ways in which liquids and gasses interact with gravity. The concept of buoyancy is connected to fundamental concepts about how the universe works. The *buoyant force*, as it is known in engineering, is an important concept that has wide ranging applications. A big part of engineering is moving stuff around, and understanding buoyancy helps us solve problems where we need to move things in and through fluids. Even if you don't have plans to build a robotic submarine, these are incredibly useful ideas to be familiar with. We will start exploring the topic with familiar scenarios around boats and water.

When you put a boat into water, it will sink into the water until the mass of the water it displaces is equal to the mass of the boat. We think of this in terms of forces. Gravity pulls the mass of the boat down; the *buoyant force* pushes the boat up. A boat dropped into the water will bob up and down at first before reaching an *equilibrium* where the two forces are equal.

The buoyant force pushes things up, fighting against the force of gravity. The force is equal to the weight of the fluid being replaced. For example, a cubic meter of freshwater has a mass of about 1000kg. If you submerge anything with a volume of one meter in freshwater on earth, the buoyant force will be about 9800 newtons (mass $\times$ gravity).

For some things, like a block of styrofoam, this buoyant force will be sufficient to carry it to the surface. Once it reaches the surface, it will continue to rise (displacing less water) until the mass of the water it displaces is equal to its mass. And then we say "It floats!"



For some things, like a block of lead, the buoyant force is not sufficient to lift it to the surface, and then we say "It sinks!"

This is why a helium balloon floats through the air. The air that it displaces weighs more than the balloon and the helium itself. (It is easy to forget that air has a mass, but it does.)

Exercise 5 Buoyancy

You have an aluminum box that has a heavy base, so it will always float upright. The box and its contents weigh 10 kg. Its base is 0.3 m x 0.4 m. It is 1m tall.

When you drop it into freshwater ($1000 \text{kg}/\text{m}^3$), how far will it sink before it reaches equilibrium?

Working Space

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3.1 The Mechanism of Buoyancy: Pressure

As you dive down in the ocean, you will experience greater and greater pressure from the water. And if you take a balloon with you, you will gradually see it get smaller as the water pressure compresses the air in the balloon.

Let's say you are 3 meters below the surface of the water. What is the pressure in Pascals (newtons per square meter)? You can think of the water as a column of water crushing down upon you. The pressure over a square meter is the weight of 3 cubic meters of water pressing down.

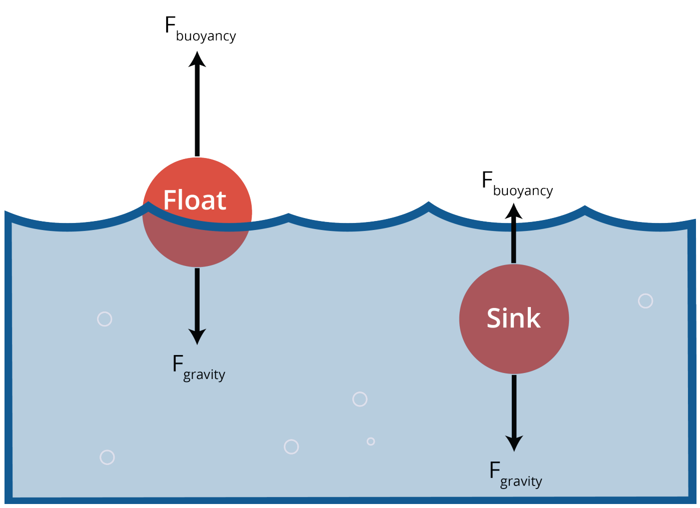
$$p = (3)(1000)(9.8) = 29,400 \text{ Pa}$$

This is called *hydrostatic pressure*. The general rule for hydrostatic pressure in Pascals p is

$p = dgh$

where d is the density of the fluid in kg per cubic meter, g is the acceleration due to gravity in m/s^2, and h is the height of the column of fluid above you.

So where does buoyant force come from? Basically, the pressure pushing up on the deepest part of the object is higher than the pressure pushing down on the shallowest part of the object. That is where bouyancy comes from.



Exercise 6 Hydrostatic Pressure

Working Space

You dive into a tank of olive oil on Mars. How much more hydrostatic pressure does your body experience at 5 meters deep than it did at the surface?

The density of olive oil is about 900 kg per square meter. The acceleration due to gravity on Mars is 3.721 m/s^2.

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3.2 The Mechanism of Buoyancy: Density

Keep in mind that although the pressure is increasing as you go deeper, the buoyant force will *not increase*, because the buoyant force is always equal to the weight of the fluid that is displaced, regardless whether that is 1 meter or 100 meters underwater.

Due to the added minerals, saltwater is denser than freshwater. This causes objects to float better in the sea than they do in a river. Lipids, like fats and oils, are less dense than water, allowing them to float on top of a glass of water. When you're facing a grease fire, you're told not to put water on it. That's because the water sinks below the grease, then boils, throwing burning grease everywhere.

Chapter 4

Heat

All mass in the universe has heat, whether you're looking at a block of dry ice (frozen CO_2, $-78.5°$ C) or the surface of the sun ($5,600°$ C). As long as the mass is above absolute zero — the coldest possible temperature in the universe — there is some amount of heat in it.

4.1 How Heat Works

As you heat up an object, you are imparting energy into it. Where does this energy go? The atoms take this energy and they begin to move, vibrating and bumping into each other, causing the heat to spread throughout. Everytime the atoms collide and bounce off of each other, they emit a tiny amount of energy as light. In most cases, that light is in the infrared spectrum, but in extreme cases can be visible, such as with molten lava or hot metal.

As objects interact, they either put heat into colder objects or take heat from warmer objects. That's what allows you to heat up anything in the first place. The hot air from a stove or bunsen burner interacts with the pan or test tube you're heating, passing the air's heat on. How could you model this?

4.2 Specific Heat Capacity

If you are heating something, the amount of energy you need to transfer to it depends on three things: the mass of the thing you are heating, the amount of temperature change you want, and the *specific heat capacity* of that substance.

Energy in Heat Transfer

The energy moved in a heat transfer is given by

$$E = mc\Delta_T$$

where m is the mass, Δ_T is the change in temperature, and c is the specific heat capacity of the substance.

(Note that this assumes there isn't a phase change. For example, this formula works nicely on warming liquid water, but it gets more complicated if you warm the water past its boiling point.)

Can we guess the specific heat capacity of a substance? It is very, very difficult to guess the specific heat of a substance, so we determine it by experimentation.

For example, it takes 0.9 joules to raise the temperature of solid aluminum one degree Celsius. So we say "The specific heat capacity of aluminum is 0.9 J/g °C."

The specific heat capacity of liquid water is about 4.2 J/g °C.

Let's say you put a 1 kg aluminum pan that is 80° C into 3 liters of water that is 20° C. Energy, in the form of heat, will be transferred from the pan to the water until they are at the same temperature. We call this "thermal equilibrium".

What will the temperature of the water be?

To answer this question, the amount of energy given off by the pan must equal the amount of energy absorbed by the water. They also need to be the same temperature at the end. Let T be the final temperature of both.

3 liters of water weighs 3,000 grams, so the change in energy in the water will be:

$$E_W = mc\Delta_T = (3000)(4.2)(T - 20) = 12600T - 252000 \text{ joules}$$

The pan weighs 1000 grams, so the change in energy in the pan will be::

$$E_P = mc\Delta_T = (1000)(0.9)(T - 80) = 900T - 72000 \text{ joules}$$

The total energy stays the same, so $E_W + E_P = 0$. This means you need to solve

$$(12600T - 252000) + (900T - 72000) = 0$$

And find that the temperature at equilibrium will be

$$T = 24°C$$

Exercise 7 Thermal Equilibrium

Just as you put the aluminium pan in the water as described above, someone also puts a 1.2 kg block of copper cooled to 10 ° C. The specific heat of solid copper is about 0.4 J/g °C.

What is the new temperature at equilibrium?

Working Space

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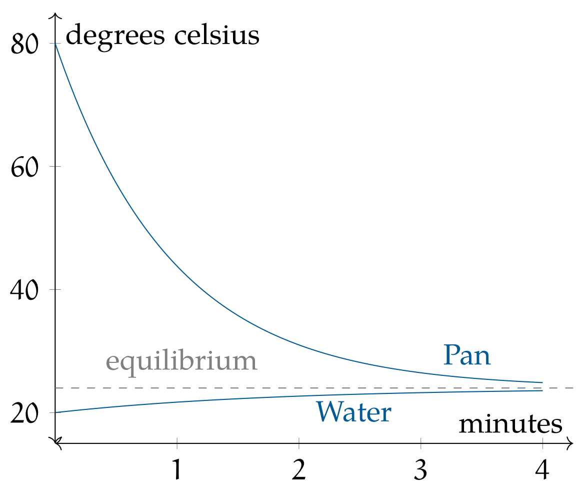
4.3 Getting to Equilibrium

When two objects with different temperatures are touching, the speed at which they exchange heat is proportional to the differences in their temperatures. As their temperatures get closer together, the heat exchange slows down.

In our example, the pan and the water will get close to equilibrium quickly, but they may never actually reach equilibrium.



Exercise 8 Cooling Your Coffee

Working Space

You have been given a ridiculously hot cup of coffee and a small pitcher of chilled milk.

You need to start chugging your coffee in three minutes, and you want it as cool as possible at that time. When should you add the milk to the coffee?

Answer on Page 35

4.4 Specific Heat Capacity Details

For any given substance, the specific heat capacity often changes a great deal when the substance changes state. For example, ice is 2.1 J/g °C, whereas liquid water is 4.2 J/g°C.

Even within a given state, the specific heat capacity varies a bit based on the temperature and pressure. If you are trying to do these sorts of calculations with great accuracy, you will want to find the specific heat capacity that matches your situation. For example, I might look for the specific heat capacity for water at 22°C at 1 atmosphere of pressure (atm).

Chapter 5

Friction

Imagine there is a large and heavy steel box resting in the middle of a floor, and you push it hard enough to get it moving. If you stop pushing, will it continue to glide gracefully across the floor?

Probably not. Unless the floor is very slippery for some reason, the box will come to a halt immediately after you stop pushing. We would say that it is stopped by the force of *friction*.

What is really happening? The kinetic energy of the box is being converted into heat between the bottom of the box and floor. As the bottom of the box and the floor get warmer, the speed of the box decreases.

The amount of friction is proportional to the force with which the box is pressing against the floor — so you should expect a box that is twice as heavy to experience twice as much frictional force.

In other words, the frictional force is proportional to the normal force. On a level floor, the normal force is parallel and equal to the force of gravity acting on the box. On a slope, the normal force points perpendicular to the surface of the slope. We will be talking about sloped surfaces in a later chapter, so focus on level surfaces for now.

(FIXME: picture here)

The amount of friction is also determined by the materials that are sliding against each other. For example, if the floor is ice, the frictional force will be less than if the floor is made of wood. Written mathmatically, we can express the force of friction as

$$F_f = \mu N$$

where F_f is the force of friction, N is the normal force (you may see written as R , F_n , or just N), and μ is a coefficient that depends on the materials in contact with each other.

If you are pushing the box with a force of F and it is moving but neither accelerating nor decelerating, then the force you are applying is exactly balanced by the frictional force. If the box is pressing against the floor with a force of N, then we say the *coefficient of friction* is given by the ratio between the weight of the steel box and the floor:

$$\mu = \frac{F_f}{N}$$

Exercise 9 Bicycle Stopping

Working Space

You are riding your bicycle on a flat, horizontal at 11 meters per second when you suddenly slam on the brakes and lock up the wheels.

You weigh 55 kg.

When any piece of rubber is skidding across a dry road, the coefficient of friction will be about 0.7.

Answer the following questions:

- How much kinetic energy do you have when you engage the brakes?
- As you skid, how much frictional force is decelerating you?
- For how many meters will you slide?

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Notice that the force of friction is not determined by how much of the tire is touching the ground. The coefficient of friction of the two materials and the normal force is all you need to compute the friction.

5.1 Static vs Kinetic Friction Coefficients

Let's return to the box on the floor we discussed earlier. As you start to push it, it will sit still until your force is greater than the force of friction. However, once it starts moving, the force of friction seems to be less.

Between the two materials, there are actually two different friction coefficients:

- Kinetic friction coefficient: The coefficient you use once the box is sliding against the floor.
- Static friction coefficient: The coefficient you use to figure out how much force you need to get the box to start to move.

The kinetic friction coefficient is always less than the static friction coefficient:

- *Kinetic*, μ_k: For a car skidding on a dry road, the friction coefficient is about 0.7.
- *Static*, μ_s: When the car is parked with its brakes on, it has a friction coefficient of about 1.0.

Exercise 10 Rocket Sled

Working Space

You are built a rocket sled with steel runners on a flat, level wooden floor. The sled weighs 50 kg and you weigh 55 kg.

Before you get on the sled, you try pushing it around the floor. You find that you can get it to move from a standstill if you push it with a force of 270 N. Once it is moving, you can keep it moving at the same speed using a force of 220 N.

What are μ_s and μ_k of your sled's runners on your wooden floor?

Next, you get on the sled and gradually increase the thrust of the rocket mounted on the sled until it starts to move. You then keep the thrust constant.

How much force was the rocket exerting on you and the sled when it started to move?

How how fast do you accelerate now that the sled is moving?

Answer on Page 35

5.2 Skidding and Anti-Lock Braking Systems

When a car goes through a curve, the friction of the tire on the road is what changes the direction of the car's travel. Even though the wheel is turning, this is the static friction coefficient because the surface of the tire is not sliding across the road.

If you go into the curve too fast, the tire may not have enough friction to turn the car. In this case the car will start to slide sideways. Now the friction between the tire and road uses the kinetic coefficient. In other words, you have significantly less friction than you had before you started to skid.

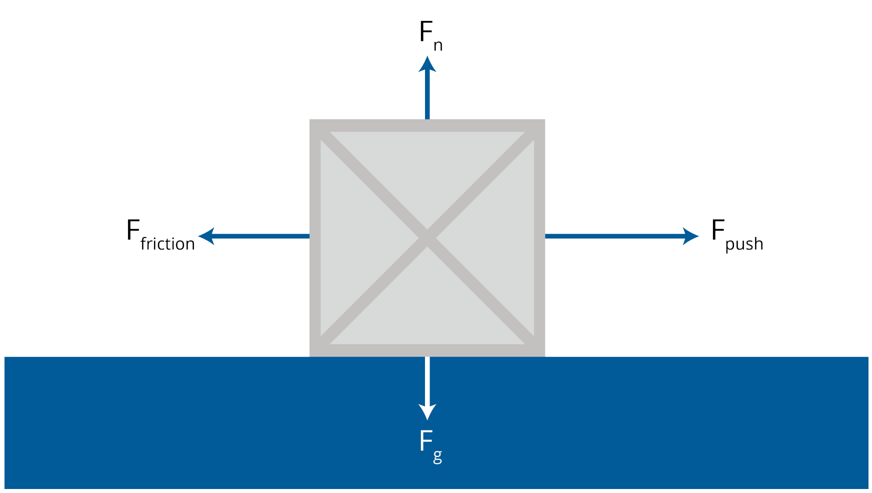
When you are driving a car, the force of friction that your tires create is your friend. It lets you steer, accelerate, and stop.

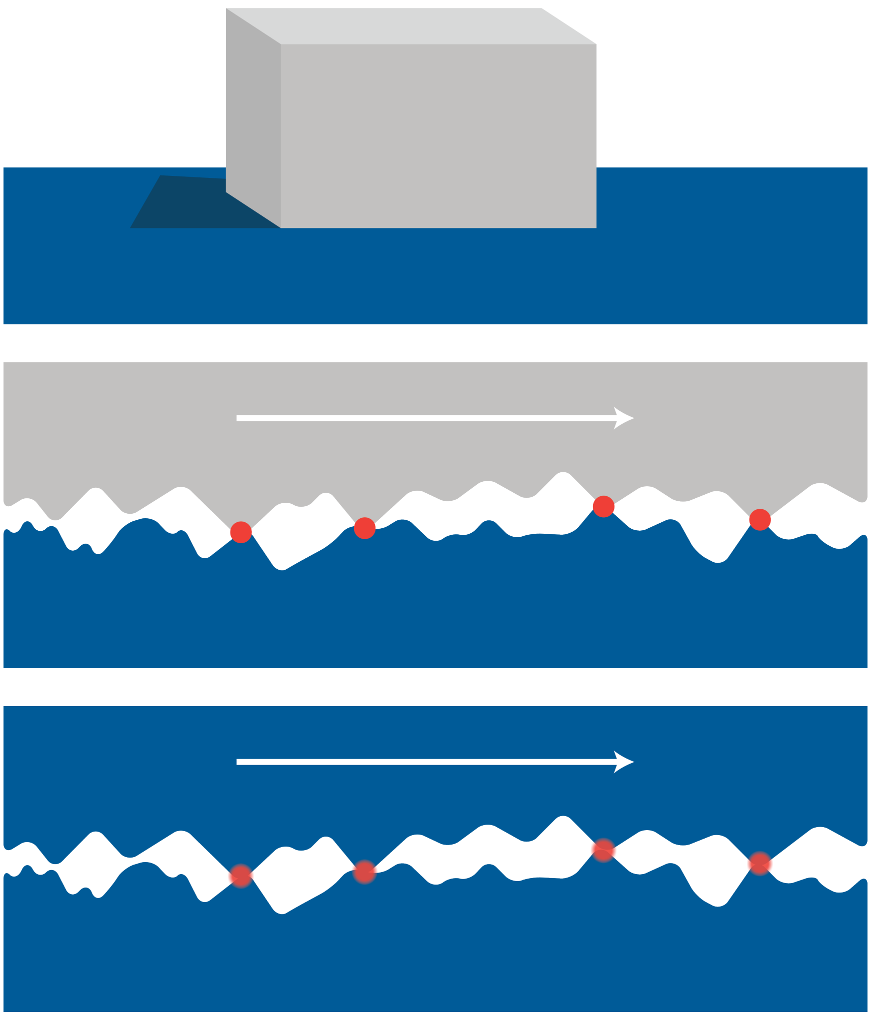
In older cars, if you would panicked and slammed on the brakes, you would probably lock up the wheels: they would stop turning suddenly. And the surface of the tire would begin to slide across the pavement. At that moment, two problems occurred:

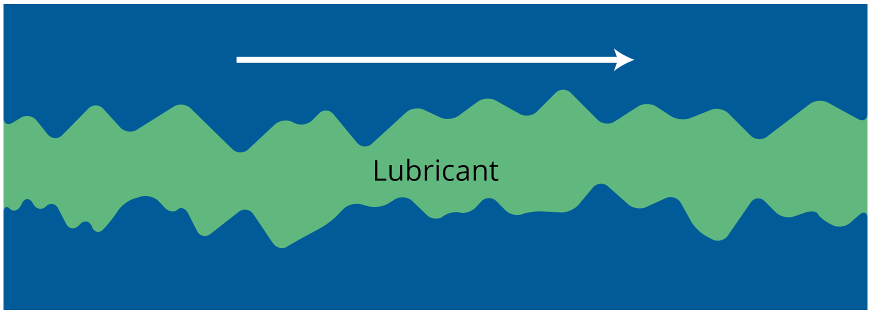
- You don't stop as quickly, because now the friction between your tires and the road is based on the kinetic friction coefficient instead of the static friction coefficient.
- You can't steer the car. Steering only happens because the wheels are turning in a particular direction.

To prevent this problem, car companies developed the anti-lock brake system, or ABS.

FIXME: More here.



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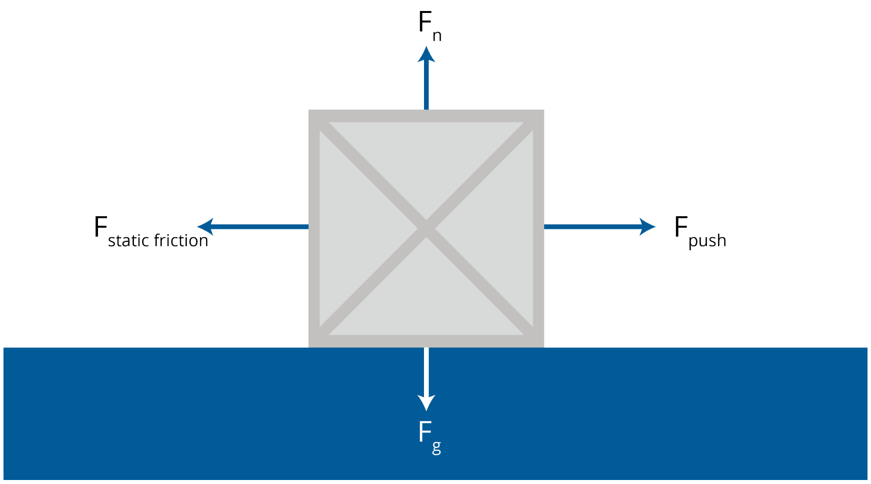
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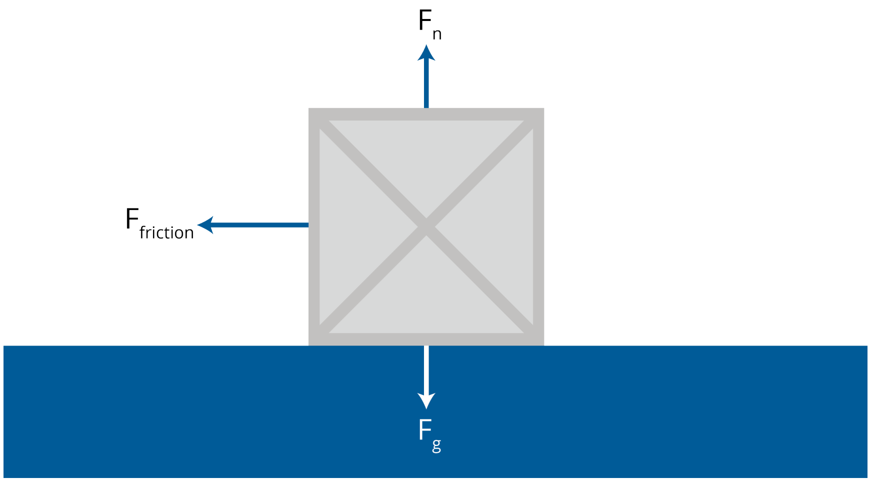
F_{push}
F_g


F n
F friction
F g

Appendix A

Answers to Exercises

Answer to Exercise 1 (on page 10)

The weight of the barrel is $136 \text{ kg} \times 9.8 \frac{\text{m}}{\text{s}^2} = 1332.8 \text{ N}$.

Let L be the length of the inclined plane. The force needed to push the barrel up is related by:

$$300 \text{ N} = \frac{2 \text{ m}}{L} \times 1332.8 \text{ N}$$

Solving for L, we find $L = \frac{2 \text{ m} \times 1332.8}{300} \approx 8.885 \text{ m}$.

Answer to Exercise 2 (on page 11)

Paul exerts a force of $70 \text{ kg} \times 9.8 \frac{\text{m}}{\text{s}^2} = 686 \text{ N}$ at a distance of 4 meters from the fulcrum, creating a torque of $686 \text{ N} \times 4 \text{ m} = 2744 \text{ N} \cdot \text{m}$. Jan exerts a force of $50 \text{ kg} \times 9.8 \frac{\text{m}}{\text{s}^2} = 490 \text{ N}$.

Let r be the distance from the fulcrum to Jan's seat. To balance the torques:

$$490 \text{ N} \times r = 2744 \text{ N} \cdot \text{m}$$

Solving for r, we find $r = \frac{2744}{490} \approx 5.6$ meters.

Answer to Exercise 3 (on page 13)

The equation relating these quantities is:

$$583 = 70 \times 2.2 \times \frac{53}{n}$$

Solving for n, we find $n = 14$ teeth.

Answer to Exercise 4 (on page 14)

We are solving for the radius r of the piston. The area of the piston is πr^2, so the pressure is:

$$\text{Pressure} = \frac{12}{\pi r^2}$$

Setting the pressure equal to 2,500,000 pascals:

$$2,500,000 = \frac{12}{\pi r^2}$$

Solving for r, we find:

$$r = \sqrt{\frac{12}{\pi \times 2.5 \times 10^6}} \approx 0.00124 \text{ meters.}$$

Answer to Exercise 5 (on page 18)

Equilibrium will be achieved when the box has displaced 10 kg of water. In other words, when it has displaced 0.01 cubic meters.

The area of the base of the box is 0.12 square meters. So if the box sinks x meters into the water it will displace $0.12x$ cubic meters.

Thus at equilibrium $x = \frac{0.01}{0.12} \approx 0.083$ m. So the box will sink 8.3 cm into the water before reaching equilibrium.

Answer to Exercise 6 (on page 20)

$$p = dgh = (900)(3.721)(5) = 16,744.5 \text{ Pa}$$

Answer to Exercise 7 (on page 23)

$$E_C = (1200)(0.4)(T - 10) = 480T - 4800$$

Total energy stays constant:

$$0 = (12600T - 252000) + (900T - 72000) + (480T - 4800)$$

Solving for T gets you $T = 23.52°$ C.

Answer to Exercise 8 (on page 24)

During the 3 minutes, you want the coffee to give off as much of its heat as possible, so you want to maximize the difference between the temperature of the coffee and the temperature of the room around it.

You wait until the last moment to put the milk in.

Answer to Exercise 9 (on page 26)

Kinetic energy? $E = \frac{1}{2}mv^2 = (.5)(55)(11^2) = 3,327.5\frac{\text{kgm}^2}{\text{s}^2} = 3,327.5$ joules.

Frictional force? $F = \mu N = (0.7)(55)(9.8) = 377.3$ newtons.

Distance? $D = \frac{3,327.5}{377.3} \approx 8.8$ seconds. (found by using $W = F_f D$ and $W = \Delta E$)

Answer to Exercise 10 (on page 28)

The empty sled is pushing directly down on the floor with a force of $(50)(9.8) = 490$ N.

The force to overcome the static friction is:

$$270 = 490\mu_s$$

Thus, $\mu_s = 0.551$

The force to match kinetic friction is:

$$220 = 490\mu_k$$

Thus, $\mu_k = 0.449$

Once you are on the sled, it is pressing directly down on the floor with a force of $(50 + 55)(9.8) = 1,029$ N.

The force to overcome the static friction is:

$$F = (1,029)(0.551) = 567 \text{ N}$$

Once the sled is moving, friction is counteracting some of your force. How much?

$$F_f = (1,029)(0.449) = 462 \text{ N}$$

All of your acceleration is due to the remaining $567 - 492 = 75$ N.

We know that $F = ma$. In this case $F = 75$ N and $m = 105$ kg. So

$$a = \frac{75}{105} = 0.714 \text{ meters per second per second}$$

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