Temperature and Heat

1. Two systems of temperature

1.1 Temperature conversions

C to F: multiply by 9/5 then add 32.

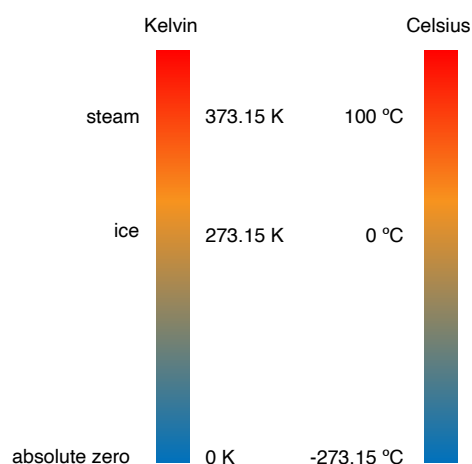F to C: Subtract 32, then multiply by 5/9.

Celsius	Fahrenheit
-30	-22
-20	-4
-10	14
0	32
10	50
20	68
30	86
40	104

Quick Question 1

When do the Celsius and Fahrenheit scales cross?

1.2 Real science (one scale to rule them all)

The Kelvin Scale.

The Kelvin scale is similar to the Celsius Scale in that there are 100 divisions between the ice point and the boiling point of water.

1.3 Temperature scales

Temperature (K)	Phenom.
0	Absolute Zero
100×10^{-12}	Lowest Lab Temperature
100×10^{-3}	My experiments
4	Boiling Point of Helium
77	Boiling Point of Nitrogen
293	Room Temperature
737.5	Mean Temperature on Venus
1670	Blue Candle Flames
5780	Sun's Surface

2. Effects of temperature on materials

2.4 Linear Thermal Expansion

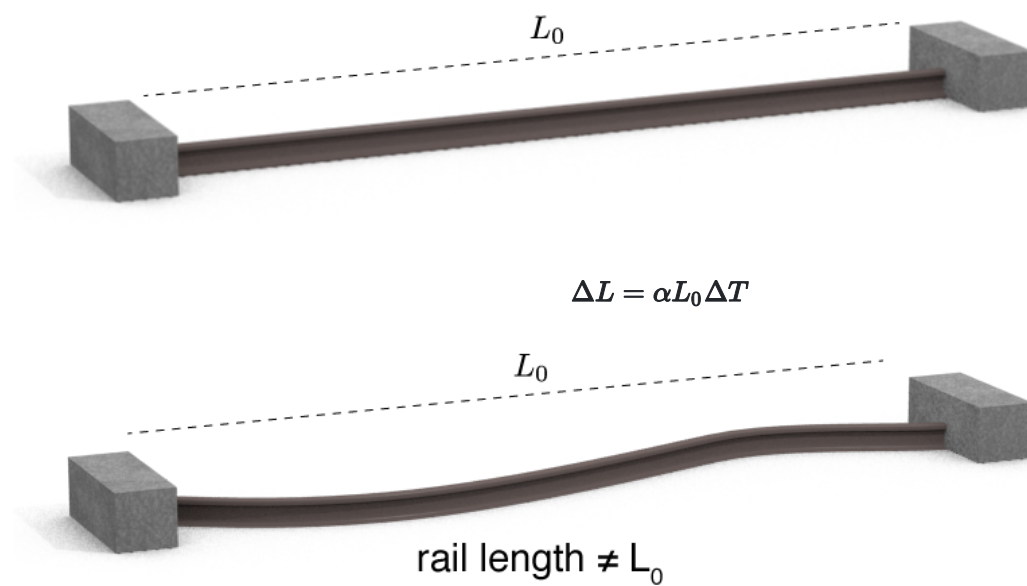The length, L_0, of a solid changes by an amount ΔL when its temperature changes by ΔT.

$$\Delta L = \alpha L_0 \Delta T$$

where α is the coefficient of linear expansion.

The coefficient α is good to know when designing structures or devices with more than one material.

Material	Linear coefficient (α)
Aluminum	23×10^{-6}
Brass	19×10^{-6}
Concrete	12×10^{-6}
Copper	17×10^{-6}
Glass	8.5×10^{-6}
Quartz (fused)	0.50×10^{-6}
Glass	8.5×10^{-6}
Iron, Steel	12×10^{-6}

2.5 Examples of linear thermal expansion

$$\Delta L = \alpha L_0 \Delta T$$

rail length ≠ L_0

2.6 The Bimetallic strip

normal T   heated

brass   steel
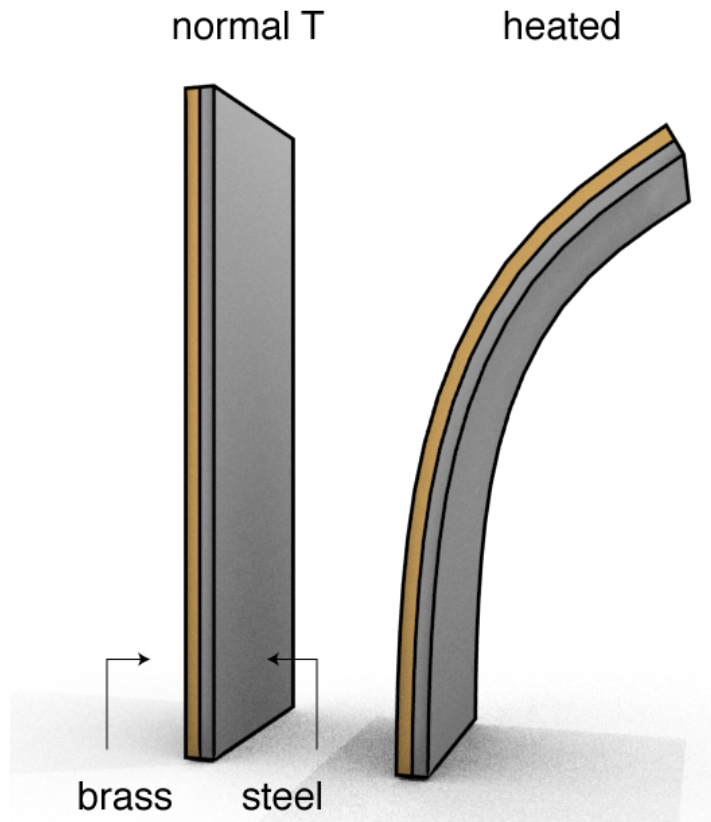
If two metals, like brass and steel and joined together into a thin sheet like so, then when heated, since the α values are different for each metal, there will be significant bending of the strip.

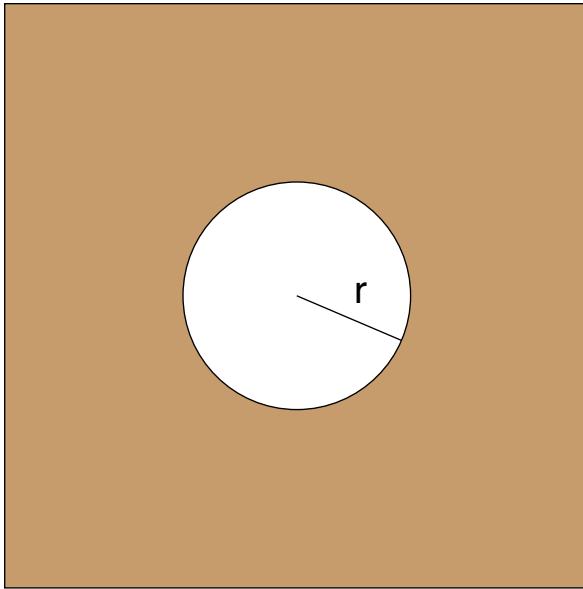$\alpha_{\text{steel}} = 12 \times 10^{-6}$

$\alpha_{\text{brass}} = 19 \times 10^{-6}$

Example Problem
#1:

The Space Needle in Seattle is 180 meters on a 0° C day. How much taller is it on a hot summer day? (Take hot to mean 30°. It's also made out of steel)

Quick Question 2

Here's a piece of material which has a positive α value. What will happen to r as the object is heated?

       a) r will get bigger

       b) r will stay the same

       c) r will get smaller

Example Problem #2:

Explain why it sometimes helps to open a glass jar with a very tight metal lid by running hot water of it.

Material	Linear coefficient (α)
Aluminum	23×10^{-6}
Brass	19×10^{-6}
Concrete	12×10^{-6}
Copper	17×10^{-6}
Quartz (fused)	0.50×10^{-6}
Glass	8.5×10^{-6}
Iron, Steel	12×10^{-6}

2.7 Volume Thermal Expansions

The volume, V_0, of a solid changes by an amount ΔV when its temperature changes by ΔT.

$$\Delta V = \beta V_0 \Delta T$$

Quick Question 3

Which one of the following statements is the best explanation for the fact that metal pipes that carry water can burst during cold winter months?

       a) Both the metal and the water expand, but the water expands to a greater extent.

       b) Water contracts upon freezing while the metal expands at lower temperatures.

       c) The metal contracts to a greater extent than the water.

d) The interior of the pipe contracts less than the outside of the pipe.

e) Water expands upon freezing while the metal contracts at lower temperatures.

3. Heat and Energy

3.8 Energy, again

Previously, we waved away the effects of 'heat'.

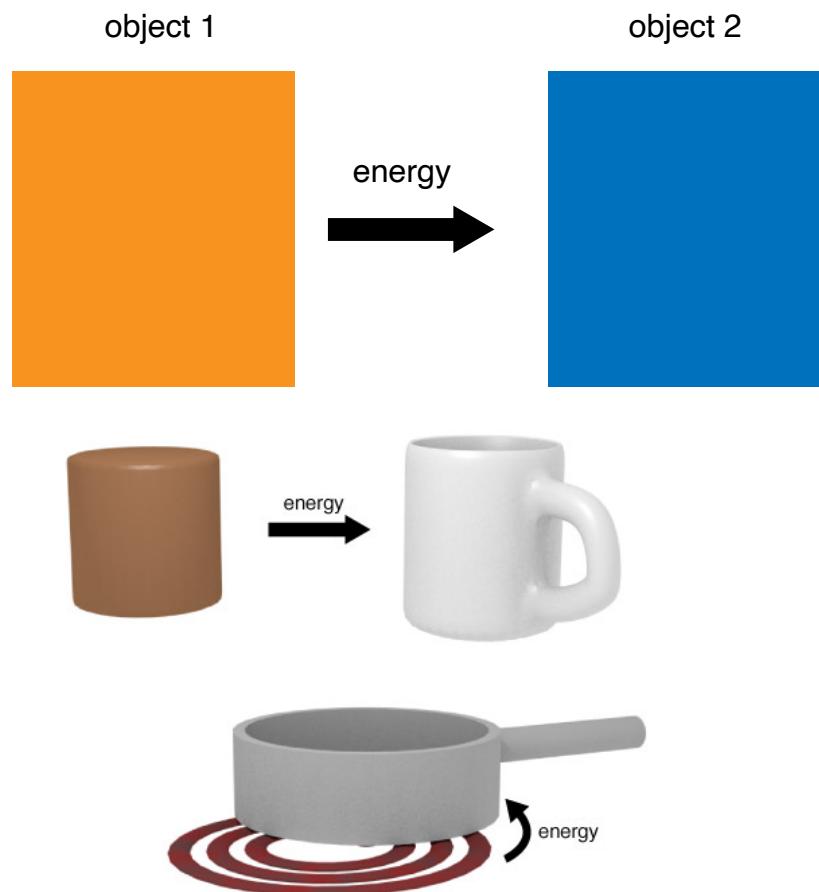We said that energy was lost due to heat, and other such things.

$$E_{\mathrm{mech}} = PE + KE$$

We could account for the lost energy, but that was about the extent of our dealings.

$$W_{\mathrm{nc}} = E_f - E_0$$

Heat: The flow of thermal energy from an object of higher temperature to an object of lower temperature.

SI unit: Joule

Let's say we want to change the temperature of an object by an amount ΔT.

We'll need to transfer some amount of heat, Q, to the object in order to make this happen.

This amount will depend on the mass, m, of the object as well as the physical makeup of the object.

$$Q = cm\Delta T$$

Here, c, is the Specific Heat .

3.9 Specific Heat

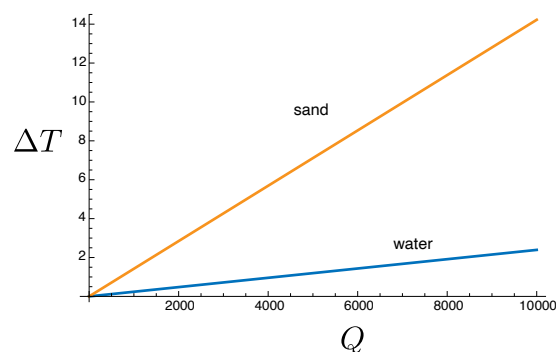| Substance	c [J kg^{-1} C^{-1}]
Solids	
Aluminum	**897**
Copper	**387**
Glass	**840**
Ice	**2110**
Lead	**128**
Silica	**703**
Liquids	
Ethyl Alcohol	**2450**
Water	**4181**

The specific heat of various materials is listed here.

(all at 25ºC and 1 atm)

Compare the effects of 10000 J of heat on 1 kg of sand vs 1 kg of water.
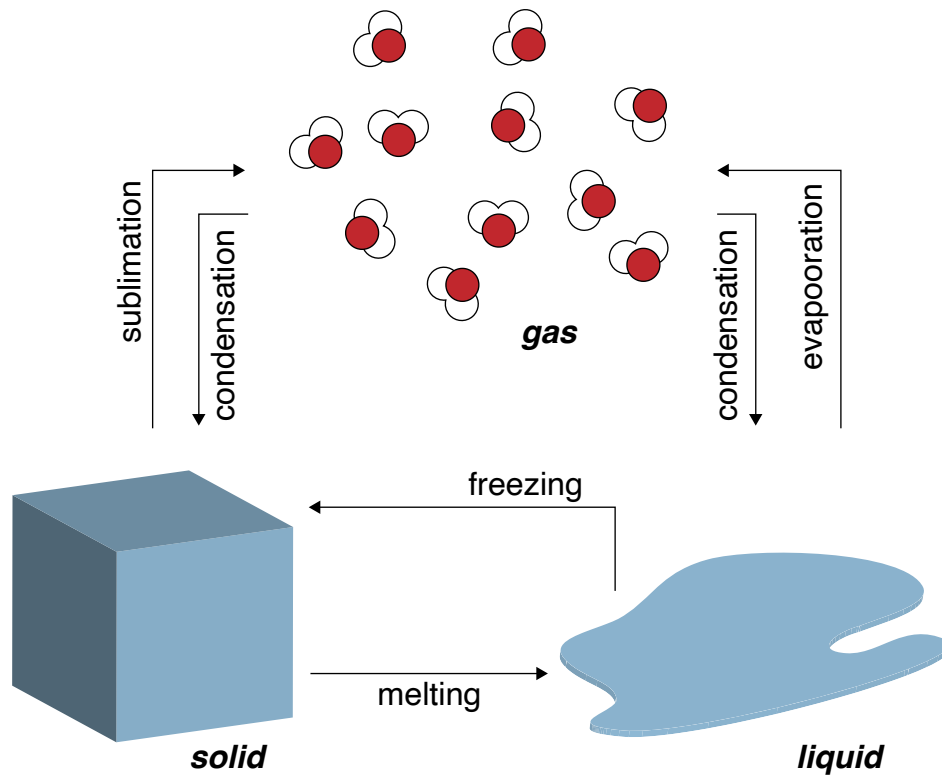

Example Problem #3:

How much heat is needed to raise a 5 kg cast-iron pot from 10 C to 90 C? What if there is also 5 kg of water in pot?
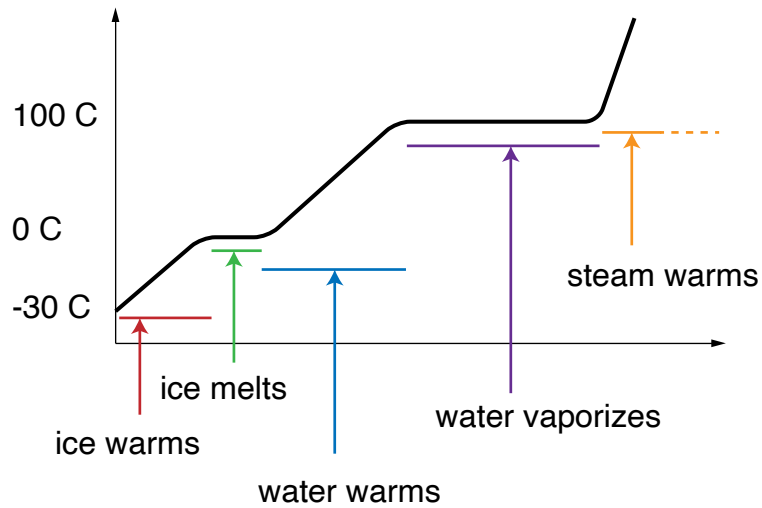
Example Problem #4:

200 cm^{3} of coffee is poured into a 150 gram glass coffee mug, which was in the cold cabinet all night and is at a temperature of 15 C. If the coffee is 95 C when it is poured into the cup, what will the final temperature of the coffee & mug system be?m

4. Phase Changes

gas

sublimation

condensation

condensation

evapooration

freezing

melting

solid

liquid

4.10 Transitions

100 C

0 C

-30 C

steam warms

ice melts
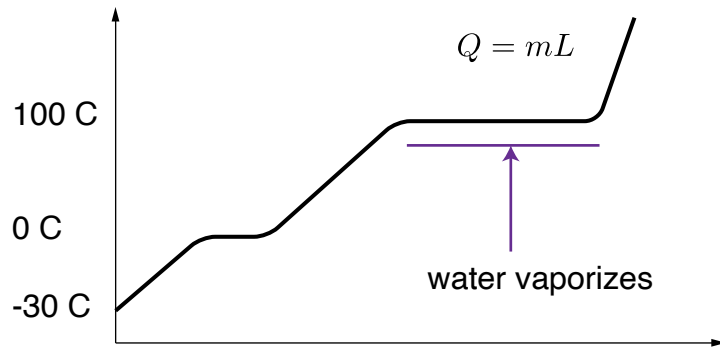
water vaporizes

ice warms

water warms

1. The ice warms up from -30 to zero
2. The applied heat melts the ice (0 C)
3. The water is warmed from 0 C to 100 C
4. The applied heat evaporates the water into steam (100 C)
5. The steam is further heated

4.11 Transitions
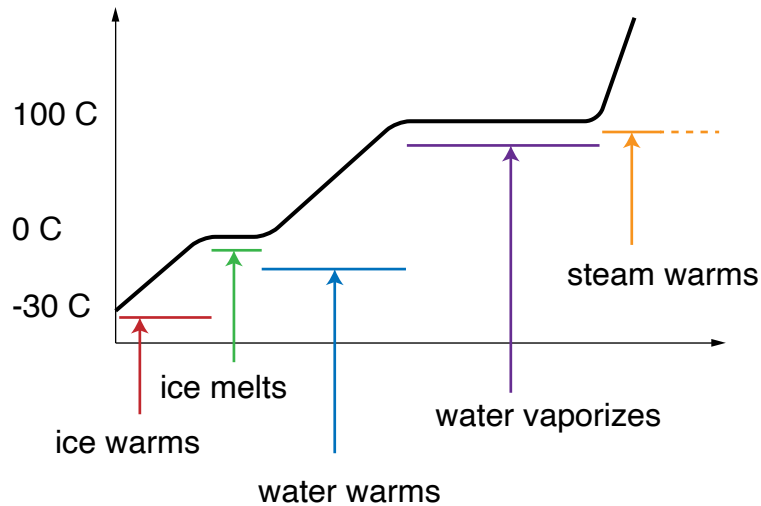
The processes during which the ice melts is a constant temperature process.

4.12 Latent Heat

$$Q = mL$$

The Latent Heat of a material tells us how much heat is needed to undergo a phase transition.

For example, the Latent Heat of Vaporization, L_V, for water is 22.6×10^5 J/kg.

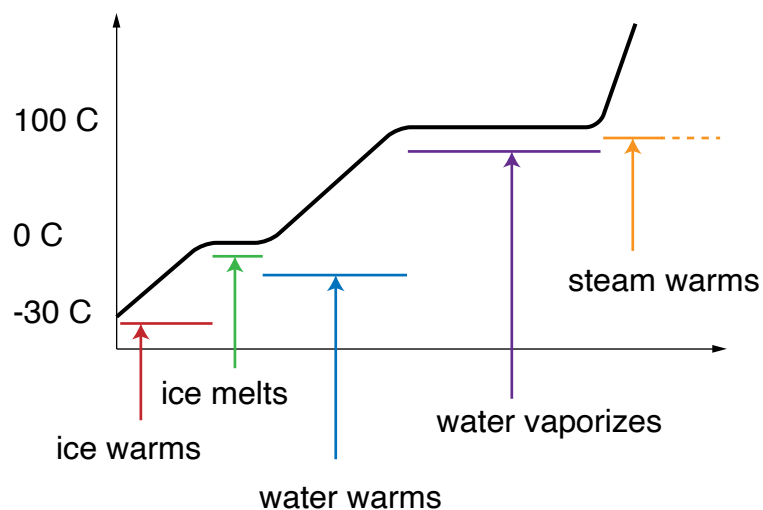Thus, to boil away 1 kg of water (~ 1 L) we would need to apply 2 260 000 J of heat

4.13 Latent Heat of Fusion

Each type of phase transition requires its own Latent Heat Value.

The latent heat of fusion refers to the transition from a solid to a liquid.

4.14 Latent Heat of Vaporization

This value tells us how much heat is required to go from the liquid to the gas phase

The length of the plateaus in this graph are indicative of the various latent heat values.
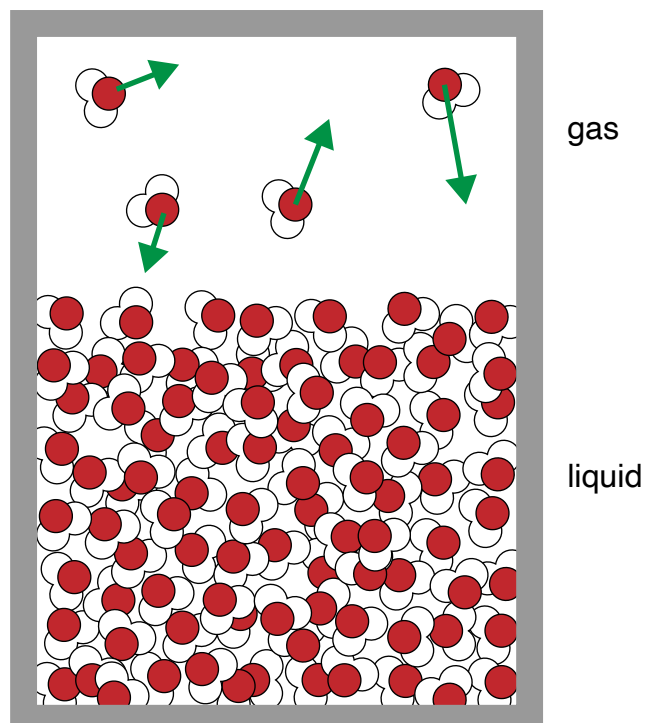
Substance	L_f	L_V
Water	33.5×10^4	22.6×10^5
Helium	x	21×10^3
Carbon Dioxide	18.4×10^4	57.4×10^4

Example Problem
#5:

Eating a popsicle is hard work. How much energy is used to bring a 45 g popsicle from the freezer temperature of -10° to body temperature?

- c (ice) = 2090 J/(kg K)
- L_f (ice) = 3.33×10^5 J/kg
- c (water) = 4190 J/(kg K)

4.15 Boiling, and vapor pressure

gas

liquid

At the boundary between a liquid and a vapor, some of the constituent molecules will be migrating back and forth between the two phases.

In a closed container, when the same number of particles are leaving the fluid as are leaving the vapor, the vapor will be at a certain pressure. This pressure is called the equilibrium vapor pressure.
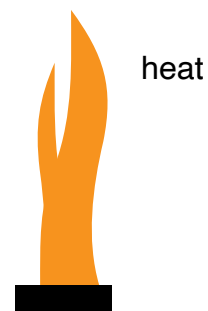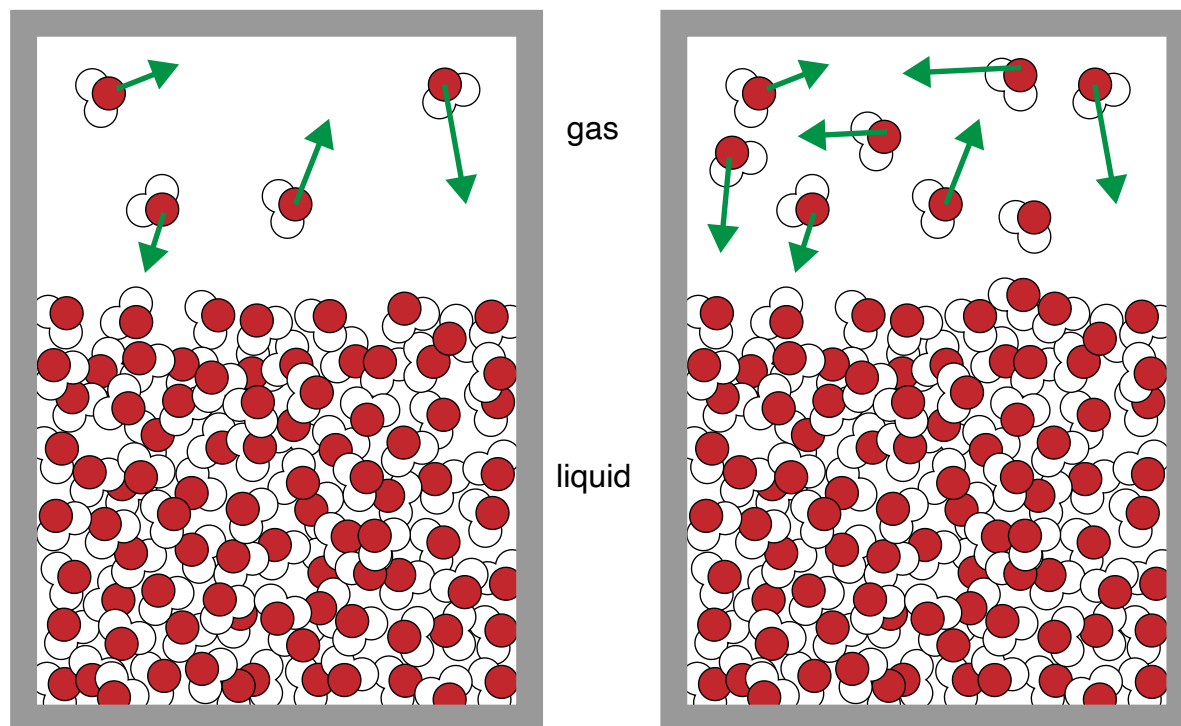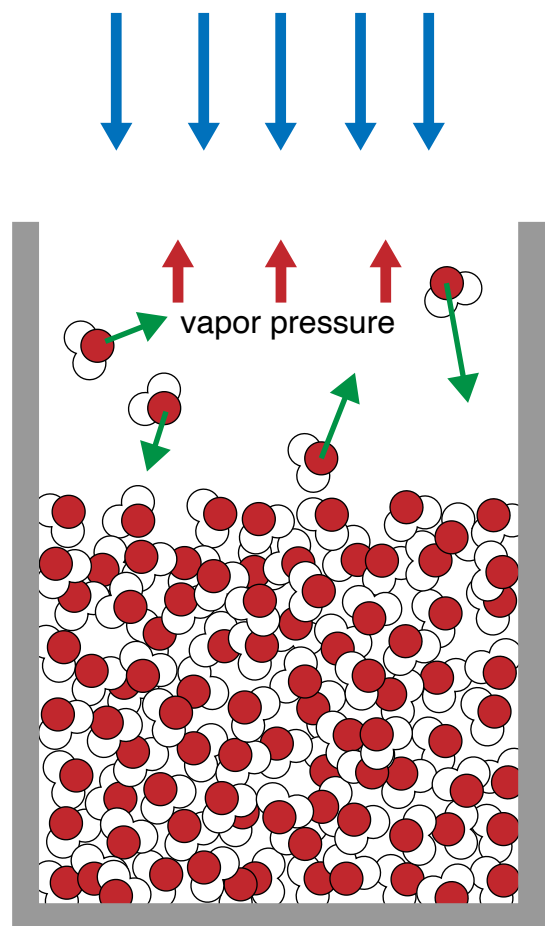

Heating the fluid will increase this vapor pressure.

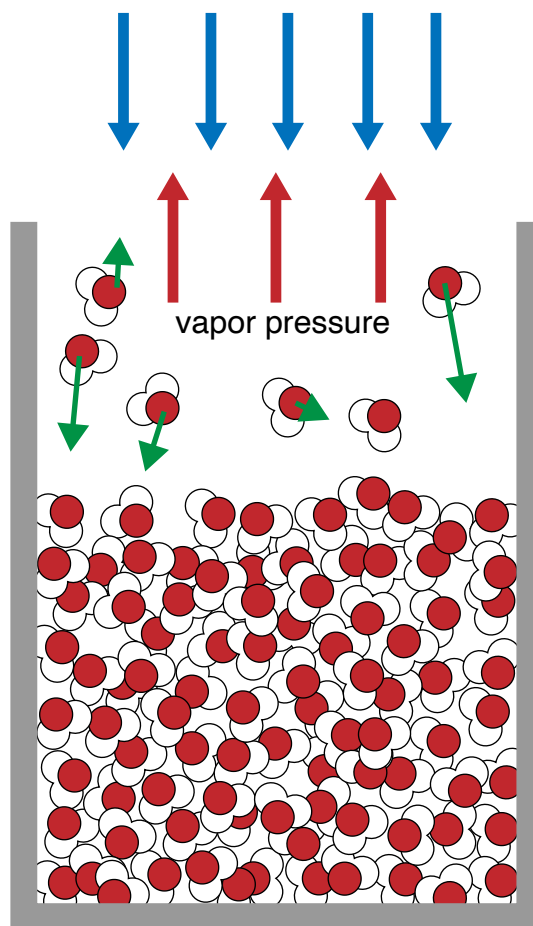The vapor pressure will be proportional to the temperature: higher temperature, higher vapor pressure.

4.16 Vapor pressure as a function of temperature.

Pressure (Pa)

101 kPa

3 kPa

24 C   100 C

Temperature (K)
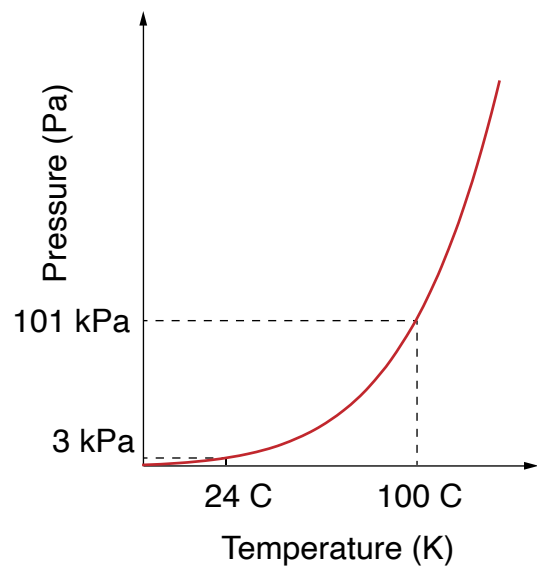
atmospheric pressure = 101325 Pa

atmospheric pressure = 101325 Pa

vapor pressure

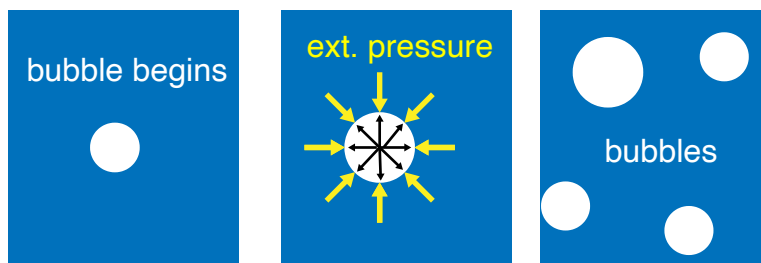gas

liquid

vapor pressure

heat

Now we take a container open to the atmosphere.

If the vapor pressure is larger than the atmospheric pressure, then we will have unrestrained transformation from liquid to vapor i.e. boiling.

vapor pressure < atmospheric
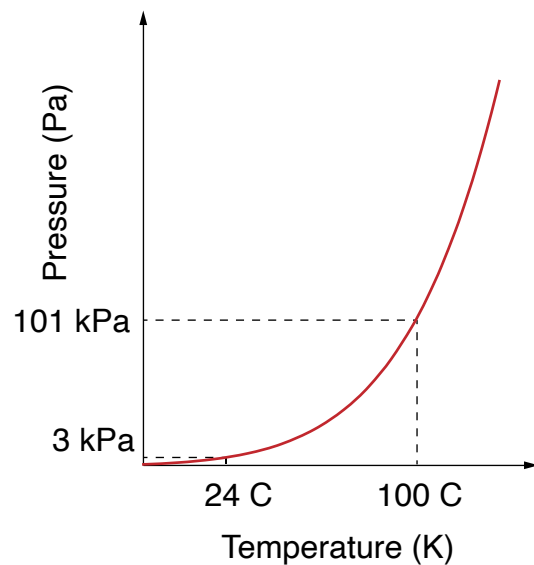

vapor pressure > atmospheric

If the pressure inside a bubble is less than the pressure outside the bubble, the bubble will collapse.

If however, the pressure inside is greater than the pressure outside, then the bubble will survive!

This is boiling.

Boiling is the unrestrained conversion of the liquid to a gas (vapor). Thus, a liquid will boil when the external pressure is equal to the vapor pressure at the given temperature.

For example, we expect water to boil at 100 C, which is when the vapor pressure equals atmospheric pressure.

On a high mountain however, where the atmospheric pressure is less, then the boiling temperature is also less.

Quick Question 4

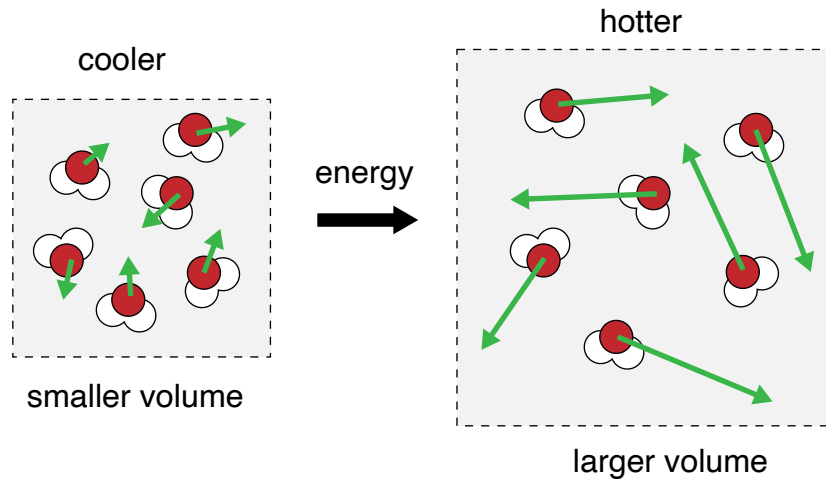What will the temperature of the water do as I remove the air from this cylinder?

a) Go up

b) Go down

c) Stay the same

5. The Transfer of Heat
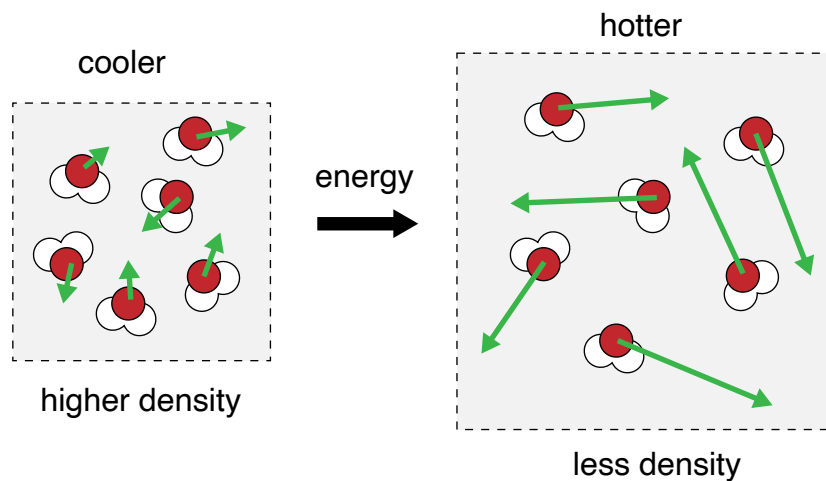
Now let's ask *how* heat is transferred.

Essentially, there are several ways we can move this motion around.

If heat is applied to a set of molecules, their thermal motion will increase.
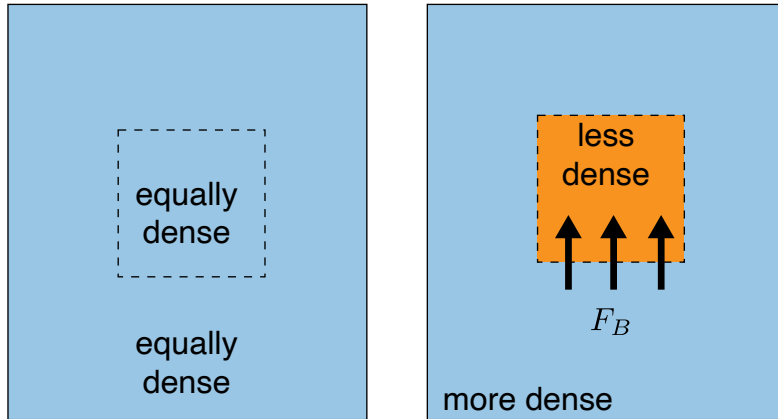

This means that there will be tendency to increase the volume of the space they fill.

Since density is given by $\rho = m/V$, if the volume goes up, the density will go down.

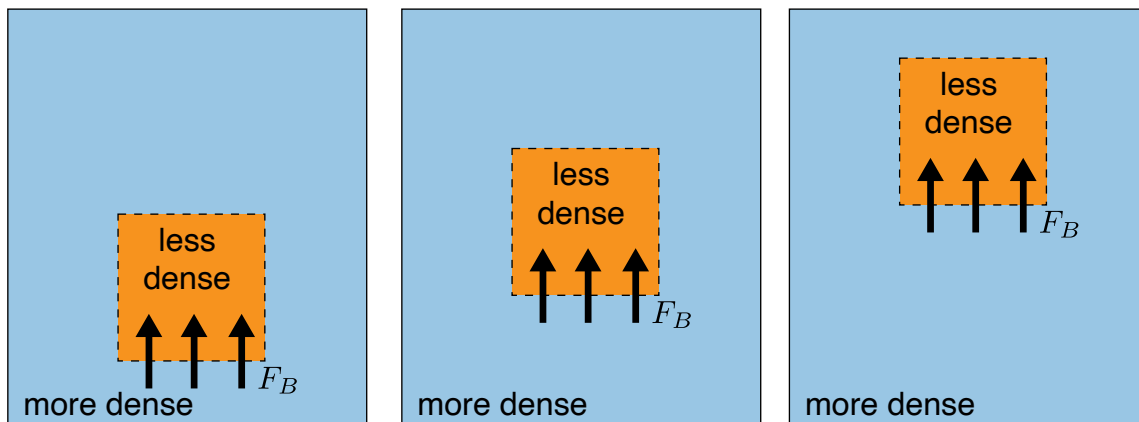Thus, heating a material will reduce the density.

5.17 Archimedes Principle

If a region of a fluid is less dense than the rest, there will be a buoyancy force on the less dense region, and that region of less dense matter will rise compared to the other parts.
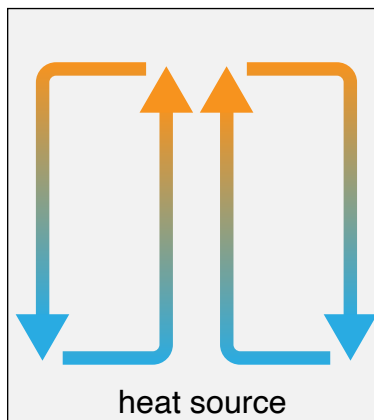
5.18 Convection

The Movement of heat via the motion of a fluid

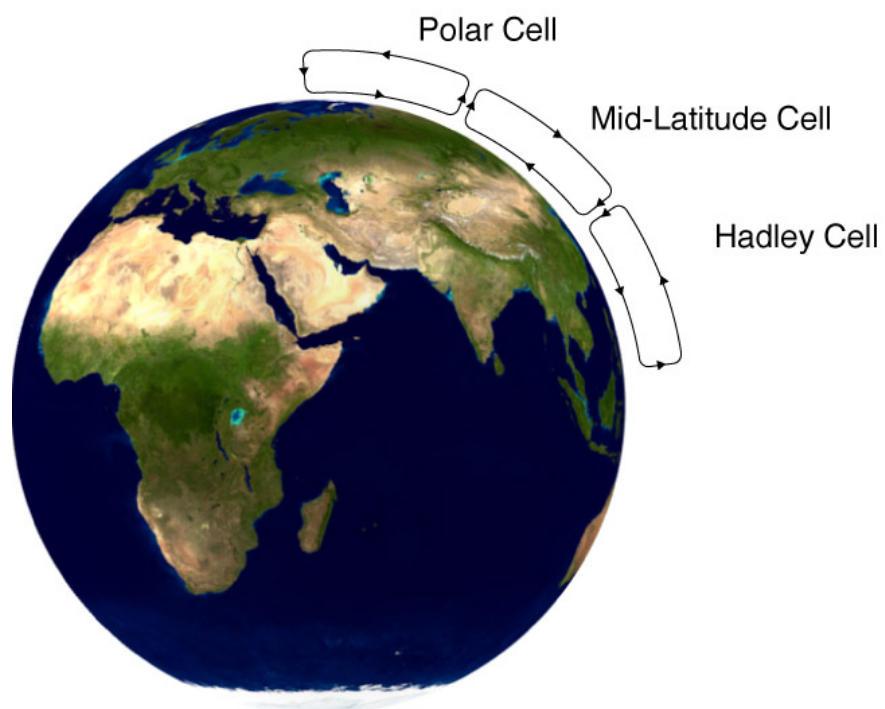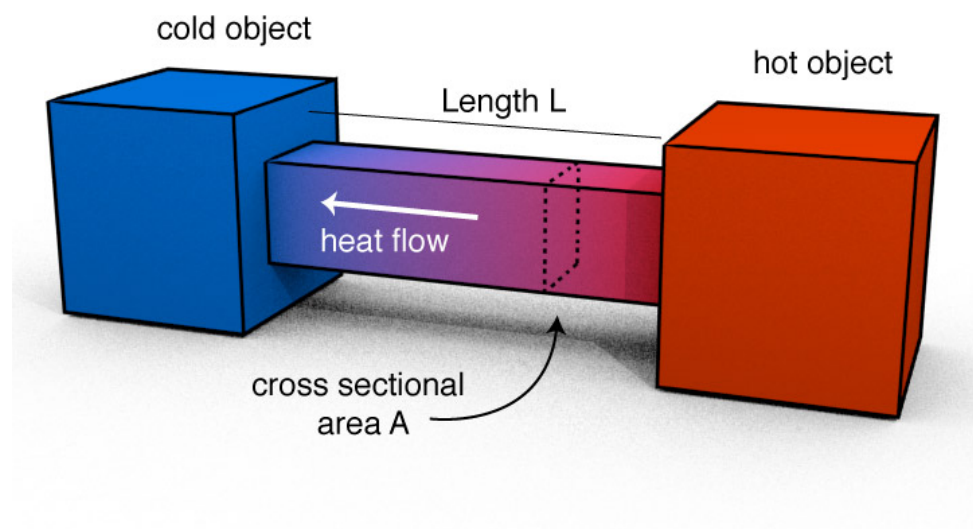## 5.19 Convection Cells

convection cells

In certain situations, this *flow* of heat can lead to the formation of convection cells.

Here, the convection current creates a cyclical behavior in the material.
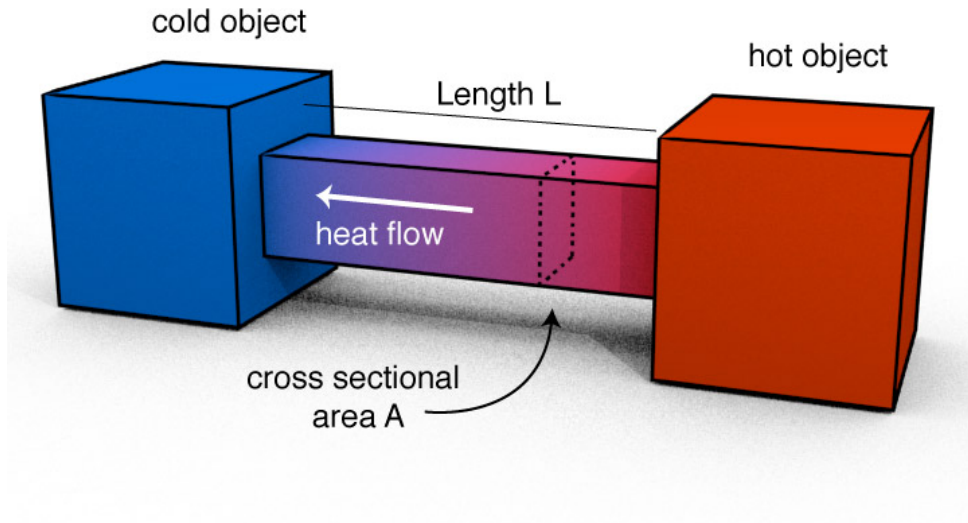
5.20 Convection Cells

Polar Cell

Mid-Latitude Cell

Hadley Cell

5.21 Conduction

cold object

hot object

Length L

heat flow

cross sectional
area A

5.22 Conduction

The amount of heat we transfer should be dependent on the following:

1. The Area of the connection. The larger A, the more heat can flow. ($Q \propto A$)
2. The length of the connection. The larger L, the less heat will flow in a given time.
3. The difference in temperature of the two objects.($Q \propto \Delta T$)
4. Some constant which describes the material. ($Q \propto k$)
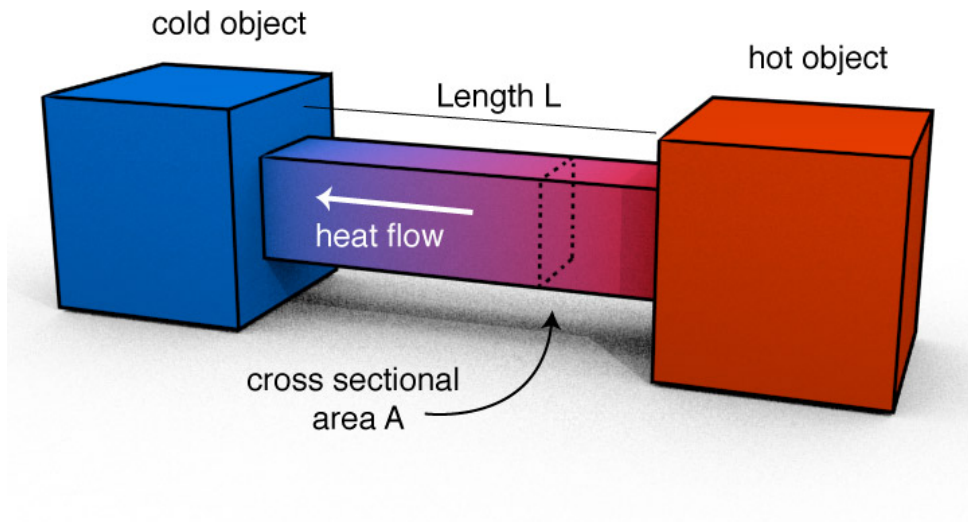
Indeed, we can express the amount of heat flow by the following:

$$Q = \frac{kA\Delta Tt}{L}$$

Some Thermal Conductivities

Substance Thermal Conductivity k [$J/(s \cdot m \cdot C°)$]

Substance	Thermal Conductivity k [$J/(s \cdot m \cdot C°)$]
Aluminum	240
Copper	390
Silver	420
Air	0.0256
Water	0.6
Wood	0.15
Styrofoam	0.0350
Vacuum	**0**

Example Problem
#6:

A freezer is insulated with styrofoam. What rate must the compressor in the back of the freezer remove heat from the freezer to keep the inside at -20 C in a 25 C room? The freezer is a cube with sides of length 0.8 meters. The styrofoam is 5 cm thick and has a k = 0.035.

Quick Question 5

Why are the coffee cup sleeves bumpy?

a) That kind of cardboard is cheaper
b) Grip is better
c) That makes for a better insulator
d) They are pleasing in apperance
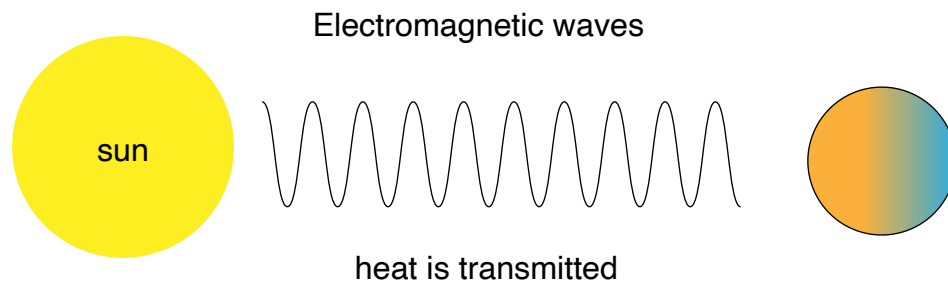e) No reason - it was an industrial accident

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5.23 Radiation

Convection and Conduction required a medium between two bodies in order for heat to flow.

However, objects can transmit energy in the form of electromagnetic waves.

The sun for example, emits EM waves and these waves transfer the energy of the sun to the earth.

There is *no medium* in outer space. But the waves don't need a medium...

Example Problem
#7:

I got a fever of 102.2 degrees F. If my mass is 70 kg, how much energy is required to make this fever happen? (I'm normally a cool 98.6 degrees)