Topic 5: Energy in Earth Processes

Topic 5 Section 1

Overview: energy, the ability to do work, is a basic attribute of the universe. Everything that happens in the universe requires or is the result of a transfer of energy. Earth has two energy systems: geothermal or internal energy and solar or energy from the Sun.

Electromagnetic energy

All matter above absolute zero will radiate or give off energy in the form of transverse waves

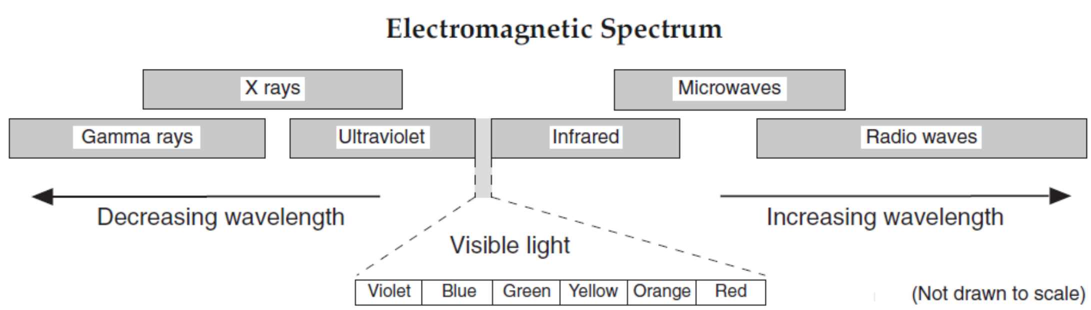
Absolute zero, 0 K or −273°C, is the theoretical lowest possible temperature

It is impossible to reach absolute zero because heat always flows from an area of higher temperature to an area of lower temperature, so you would have to have someplace with a temperature lower than zero average kinetic energy to put the last bit of heat

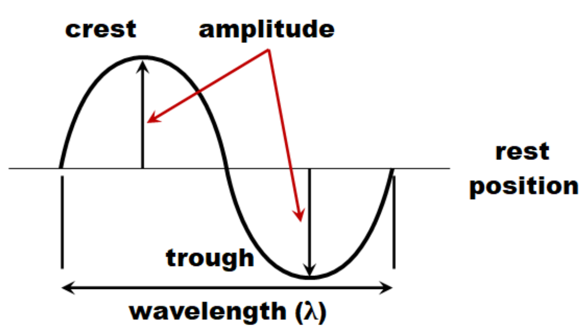
Waves can be:

- transverse – vibrate at right angles to the direction of wave travel
  examples: electromagnetic waves, secondary earthquake waves, waves in a string
- longitudinal – vibrate parallel to the direction of wave travel
  examples: sound waves, primary earthquake waves, tsunami waves
- combination – are both transverse and longitudinal at the same time
  examples: Rayleigh surface waves, seismic waves, or water waves

7 types of electromagnetic waves:



Physical Setting/Earth Science Reference Tables — 2011 Edition



Different types of electromagnetic energy are classified by wavelength

Wavelength – the distance over which the wave's shape repeats – from crest to crest or from upward rest position to upward rest position (skip through the downward rest position)

Electromagnetic spectrum – any model that shows the types of electromagnetic energy based on wavelength

Visible light is a small part of the electromagnetic spectrum that can be observed by the human eye

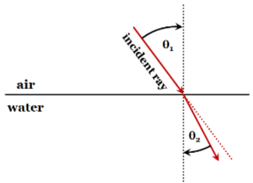
Electromagnetic energy with wavelengths shorter than visible light is called *short wave radiation* and wavelengths longer than visible light are called *long-wave radiation*

Interactions between electromagnetic energy and the environment

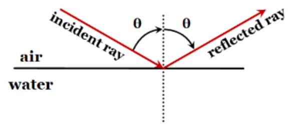
Topic 5: Energy in Earth Processes

Waves that contact a material interact with that material:

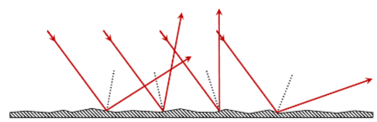
- refraction – light bends as it passes through the material (straw in a glass of water)
- reflection – light bounces off the material (mirrors)
- scattering – light is refracted/reflected in a random manner (snow)
- transmission – light passes through the material (windows)
- absorption – light energy is trapped in the material (asphalt heats up in sunlight)



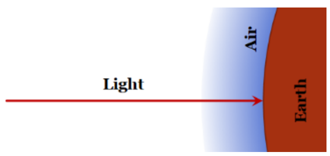
Refraction



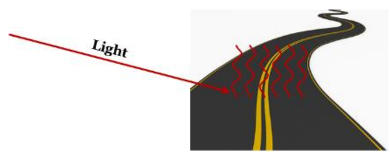
Reflection



Scattering



Transmission



Absorption

Surface properties and absorption

- texture – rough surfaces absorb better and faster
- color – dark colors absorb better and faster

The better a surface absorbs radiation, the better it will radiate energy

Topic 5 Section 2

Transfer of energy

Energy moves from high concentration to low concentration

Energy transfers from higher temperature to lower temperature involve *heat energy*

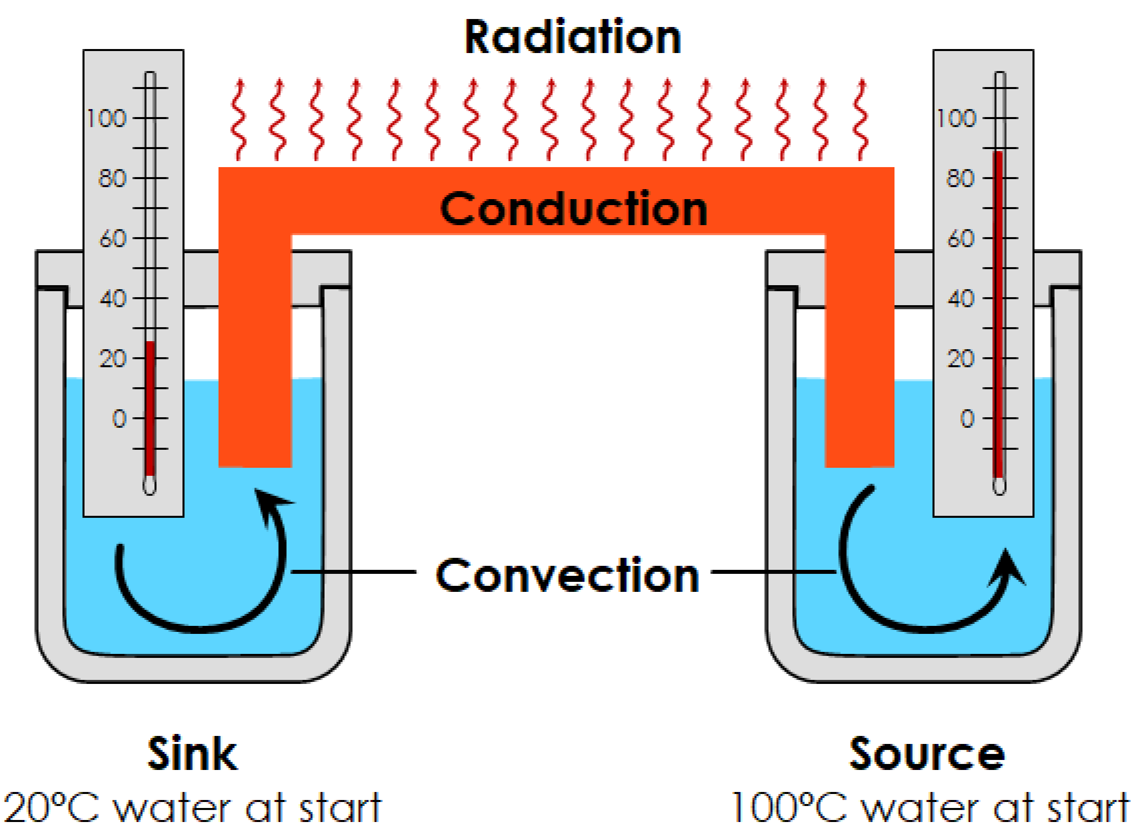
Heat transfers thermal energy

Heat continues to move from the *source* to the *sink* until their temperatures are equal or, another way to say it, until they reach dynamic equilibrium

At dynamic equilibrium, energy is still being transferred, but the rate of transfer is equal in both directions – there is no net change in heat

Methods of heat transfer:

- conduction – transfer of energy from atom to atom or molecule to molecule when vibrating particles collide – most effective in solids where particles are closer together
- convection – movement of fluids (gases and liquids) in a gravity field caused by differences in density – almost all fluids expand as they are heated which lowers the density causing less pull by gravity; more dense portions are pulled downward while less dense portions rise resulting in circulation of the fluid or a *convection current*
- radiation – energy transfer by means of electromagnetic waves – this is the only means of energy transfer that does not require a medium – the higher an object's temperature, the more energy it will radiate



Topic 5 Section 3

Transformation of energy

On Earth, energy is often transformed due to friction:

- as glaciers scrape across valley walls and floors
- as wind blows across water and causes waves

In both examples, heat forms at the interface

Heat related to the individual motions of atoms and molecules is *thermal energy*

Thermal energy is also called *internal energy*, *Q*

Internal energy is related to temperature

Internal energy is the total energy related to individual motions of atoms and molecules

Internal energy is usually related to friction

Temperature is the average kinetic energy of individual motions of atoms and molecules

Transformation of mechanical energy

Mechanical energy is all the energy of a system except the internal energy

Mechanical energy is the sum of the kinetic energy, *KE*, and potential energy, *PE*

Mechanical energy = KE + PE

The total energy of a system, E_T, equals the sum of the mechanical and internal energy

$E_T = KE + PE + Q$

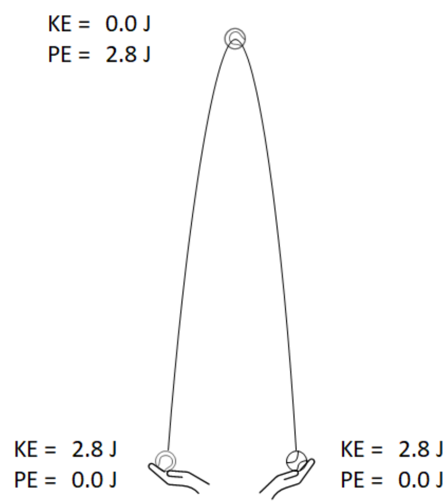
$KE = ½ mv^2$, or *KE* is related to the mass and speed of an object

PE is stored energy and can be chemical bond energy or gravitational energy, among other forms of potential energy

In Earth science, *PE* is usually gravitational *PE*

Conservation of energy says that the total energy of a system is a constant

Suppose a person throws a ball into the air and the ball reaches a maximum height of 2.0 meters, then the person catches the ball at the same height at which it was released



The ball will have a minimum PE of 0 J and a maximum speed of 6.3 m/s when it is released and a KE of 2.8 J

The ball will slow down as it rises until it stops moving up at a height of 2.0 m

At maximum height, the ball has a speed of 0 m/s, a KE of 0 J, and a PE of 2.8 J

At the moment the ball hits the catcher's hand, it will have a speed of 6.3 m/s, a KE of 2.8 J and a PE of 0 J

Transformation of electromagnetic wavelength

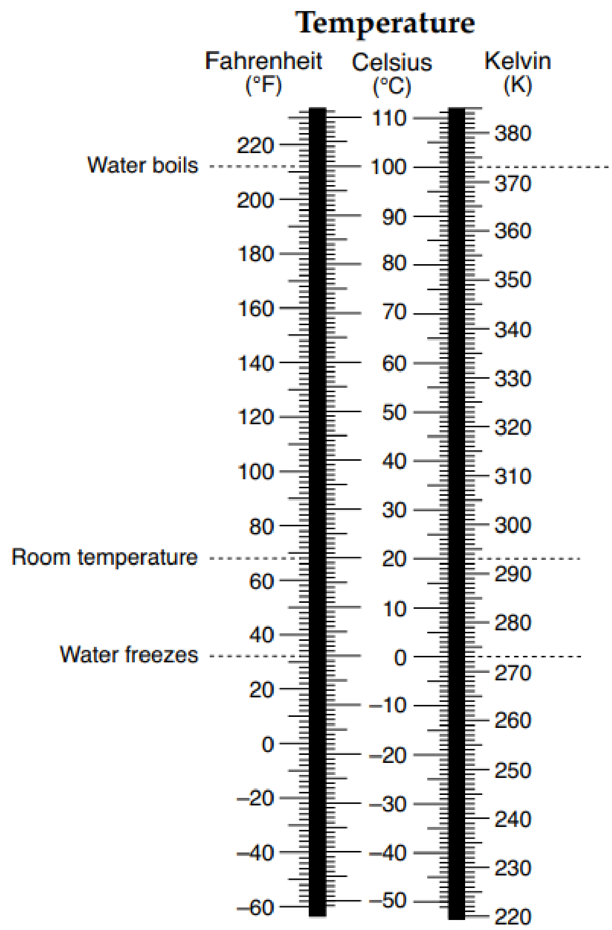
A common example of wavelength transformation occurs when shorter wavelengths from the Sun, visible and ultraviolet light, are absorbed by objects on Earth and then the energy is reradiated by the object as heat or infrared wavelengths

Objects with more energy, the Sun or things at a high temperature, radiate more energy at shorter wavelengths

Objects with less energy, rocks and sand on Earth, are at a lower temperature and radiate most of their energy at longer infrared wavelengths

Temperature and heat

- Temperature of a region or object is directly related to the amount of heat or thermal energy of the region or object
  - Temperature is a measure of the average kinetic energy of the particles in a body of matter
    - Temperature is **NOT** a type of energy
    - Some particles in a body of matter will have higher KE and others will have lower KE
    - Humans have senses that react to temperature as hot or cold
    - To accurately measure the temperature, use a thermometer
    - The NYS ESRT have a chart to convert between the three common temperature scales in use in the USA – Fahrenheit, Celsius, and Kelvin
    - Example: write the value for room temperature in Fahrenheit, Celsius, and Kelvin units
      - 68°F, 20.°C, and 293 K



Physical Setting/Earth Science Reference Tables 2011 Edition Page 12

Heat and thermal energy

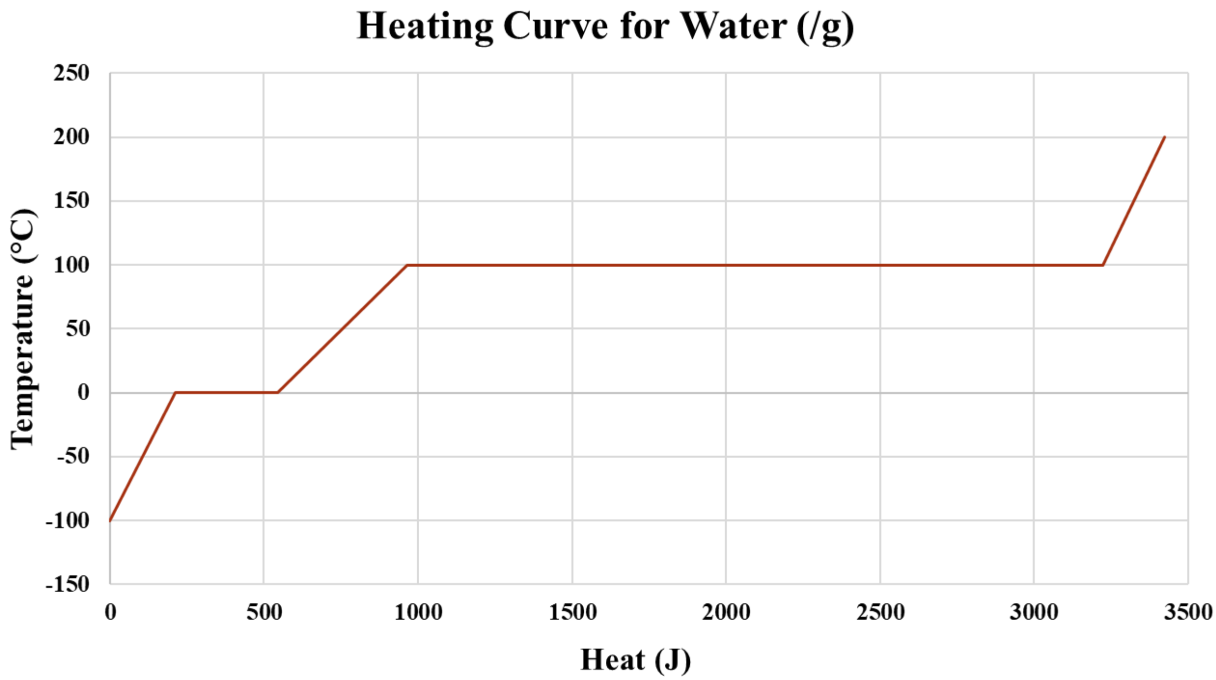
- Remember that the net flow of thermal energy is always from an object at higher temperature to an object at lower temperature
  - The type of energy transferred is called heat
  - Heat energy is measured in joules (J)
    - The *joule* is the metric unit of energy or work

Specific heat

- The amount of heat required to raise one gram of any substance one degree Celsius is called the *specific heat* of that substance
- Liquid water has the highest specific heat of any naturally occurring substance, 4.18 J/g•K while a typical rock has a specific heat of about 0.84 J/g•K
  - The high specific heat of water explains why large bodies of water have a moderating effect on the temperature of nearby regions – it takes far more heat to change the temperature of the water than it does to change the temperature of the surrounding land

Topic 5 Section 4

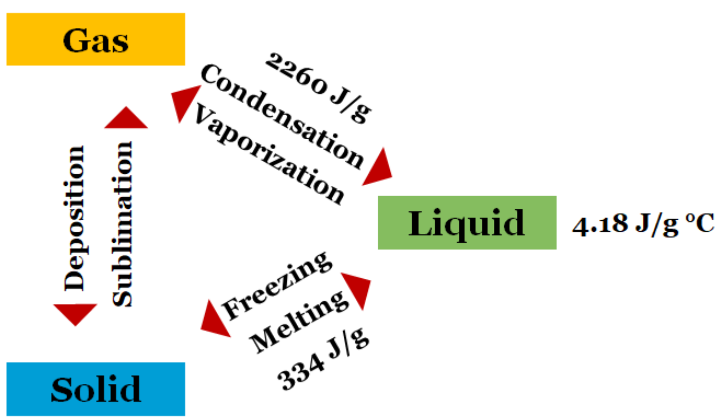
Heat energy and changes of state



Notice that there are two places on the heating curve where the temperature remains constant

- at the freezing point (0°C) – ice is melting, chemical bonds are weakening, a PE change
- at the boiling point (100°C) – liquid water is vaporizing, bonds are breaking, a PE change

Notice that at all other points on the graph, a single phase of water is changing temperature or is increasing the average KE



To change from a solid to liquid or from a liquid to a gas, water must *gain* heat
Bond breaking is *always endothermic*

To change from a gas to liquid or from a liquid to a solid, water will *lose* heat
Bond formation is *always exothermic*

Phase changes are *always* PE changes

Temperature changes are *always* KE changes

Topic 5: Energy in Earth Processes

To calculate the amount of change in energy of water, refer to NYS ESRT:

Specific Heats of Common Materials

MATERIAL	SPECIFIC HEAT (Joules/gram • °C)
Liquid water	4.18
Solid water (ice)	2.11
Water vapor	2.00
Dry air	1.01
Basalt	0.84
Granite	0.79
Iron	0.45
Copper	0.38
Lead	0.13

Properties of Water

Heat energy gained during melting	334 J/g
Heat energy released during freezing	334 J/g
Heat energy gained during vaporization	2260 J/g
Heat energy released during condensation	2260 J/g
Density at 3.98°C	1.0 g/mL

Physical Setting/Earth Science Reference Tables — 2011 Edition, Page 1

Describe the change in heat when 1.0 g of water melts at 0°C

1.0 g of water must gain 334 J to melt at 0°C

Earth's energy supply

There are two main sources of Earth's energy supply

External – Sun which supplies most of Earth's energy

$$^{0}_{-1}\beta \longrightarrow 2\gamma$$

$$+$$

$$^{1}_{1}H + ^{1}_{1}H \longrightarrow ^{2}_{1}H + \nu + ^{0}_{+1}\beta$$

$$+$$

$$^{1}_{1}H \longrightarrow ^{3}_{1}He + \gamma$$

$$+ \longrightarrow ^{6}_{4}Be \longrightarrow ^{4}_{2}He + 2\,^{1}_{1}H$$

$$^{1}_{1}H \longrightarrow ^{3}_{1}He + \gamma$$

$$+$$

$$^{1}_{1}H + ^{1}_{1}H \longrightarrow ^{2}_{1}H + \nu + ^{0}_{+1}\beta$$

$$+$$

$$^{0}_{-1}\beta \longrightarrow 2\gamma$$

Internal – radioactive or nuclear decay which supplies a small amount of Earth's energy

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{89}_{36}Kr + ^{144}_{56}Ba + 3\,^{1}_{0}n$$