Module 3

Targets/Objectives

At the end of the lesson, students should be able to:

- Discuss the energy transformation between different forms of energy.
- Explain the change in potential and kinetic energy in different situation.
- Discuss work done by a system and heat transfer between objects.
- Discuss the importance of specific heat in the environment.
- Compute work, heat transfer and energy change in a system.
- Calculate the heat capacity and heat flow between two objects.

Lecture Guide

Energy

Energy, in physics, the capacity for doing work. It may exist in potential, kinetic, thermal, electrical, chemical, nuclear, or other various forms. There are, moreover, heat and work—i.e., energy in the process of transfer from one body to another.

Two Major Forms of Energy

Kinetic energy is the energy in moving objects or mass. Examples include mechanical energy, electrical energy etc.

Potential energy is any form of energy that has stored potential that can be put to future use.

Forms of Energy

Chemical Energy is the potential of a chemical substance to undergo a transformation through a chemical reaction to transform other chemical substances. Examples include batteries, food, gasoline and etc.

Thermal energy comes from a substance whose molecules and atoms are vibrating faster due to a rise in temperature. Heat energy is another name for thermal energy.

Mechanical Energy is the sum of potential energy and kinetic energy. It is the energy associated with the motion and position of an object.

Electrical Energy is caused by moving electric charges called electrons.

Sound Energy is produced when an object vibrates. The sound vibrations cause waves of pressure that travel through a medium, such as air, water, wood or metal.

Light Energy is electromagnetic radiation within a certain portion of the electromagnetic spectrum. The word usually refers to visible light, which is the visible spectrum that is visible to the human eye and is responsible for the sense of sight

Nuclear Energy is defined as energy that comes from changes in the nucleus of an atom.

- Nuclear fission - is splitting the nucleus apart. This is the most common type of nuclear energy on earth. Nuclear reactors use fission to create their energy as does the atom bomb.
- Nuclear fusion- happens when the nuclei of two different atoms are pressed together (fused) to form a new atom.

Energy Transformations

Energy transformation, also known as energy conversion, is the process of changing energy from one form to another. Examples of energy transformation

1. Rubbing hands together to make them warm- kinetic energy to thermal energy.
2. Using a battery-powered flashlight- Chemical energy to electrical energy (in the battery) Electrical energy to radiant energy (in the bulb).
3. An object speeding up as it falls- Gravitational potential energy to kinetic energy.
4. Toaster oven - transforms electrical energy into thermal energy.
5. A blender -transforms electrical energy into mechanical energy.
6. The sun transforms nuclear energy into ultraviolet, infrared, and gamma energy all forms of electromagnetic energy.
7. Our bodies convert chemical energy from food into mechanical energy to allow us to move.
8. A natural gas stove converts chemical energy from burning into thermal energy used to cook food.

Law of Conservation of Energy

The law of conservation of energy states that energy cannot be created or destroyed, although it can be changed from one form to another.

Example: When the biker is resting at the summit, all his original energy is still around. Some of the energy is in the form of potential energy, which he will use as he coasts down the hill. Some of this energy was changed to thermal energy by friction in the bike. Chemical energy was also changed to thermal energy in the biker's muscles, making him feel hot. As he rests, this thermal energy moves from his body to the air around him. No energy is missing--- it can all be accounted for.

Potential energy is converted into kinetic energy

Before the yo-yo begins its fall, it has stored energy due to its position. At the top it has its maximum potential energy. As it starts to fall the potential energy begins to be changed into kinetic energy. At the bottom its potential energy has been converted into kinetic energy so that it now has its maximum kinetic energy.

A waterfall has both potential and kinetic energy. The water at the top of a Falls has stored potential energy. When the water begins to fall, its potential energy is changed into kinetic energy.

Explain how energy transformation occurs when you turn on a flashlight?

Chemical Energy (batteries). When you turn on the switch, Chemical Energy transforms into Electrical Energy. Electrical Energy is then transformed to Light Energy. Light Energy is transformed into Heat Energy (thermal) **Generating Electrical Energy**

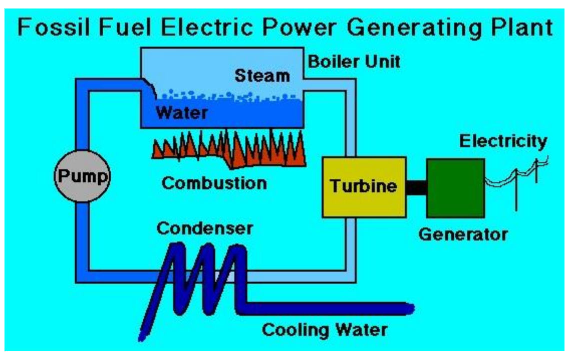


Figure 1. Fossil fuel electric power generating plant. Ophardt, C.(2003). Electricity Generation. Virtual Chembook, Elmhurst College. Retrieved from http://chemistry.elmhurst.edu/vchembook/193sources.html

Every Power plant works on the same principle---energy is used to turn a large generator. A generator is a devise that transforms kinetic energy into electrical energy. In fossil fuel power plants, coal, oil, or natural gas is burned to boil water. As the hot water boils, the steam rushes through a turbine, which

contains a set of narrowly spaced fan blades. The steam pushes on the blades and turns the turbine, which in turn rotates a shaft in the generator to produce the electrical energy.

HEAT

- Is the flow of energy between two objects, from the warmer one to the cooler one, because of a difference in their temperatures.
- Is a process not a quantity

The units of heat are therefore the units of energy, or joules (J).

Heat is transferred by conduction, convection, and/or radiation.

**All energy flow is either work or heat

Heat by Conduction

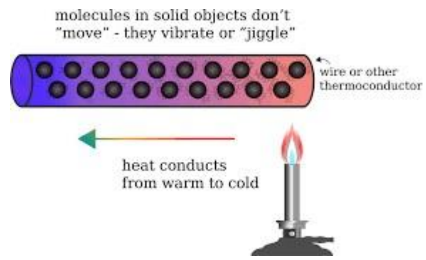


Figure 2. Heat by Conduction. Science News (2017). Retrieved from

https://taylorsciencegeeks.weebly.com/blog/methods-of-heat-transfer-conduction

Conduction occurs when two objects at different temperatures are in contact with each other. Heat flows from the warmer to the cooler object until they are both at the same temperature. Conduction is the movement of heat through a substance by the collision of molecules.

Heat by Convection

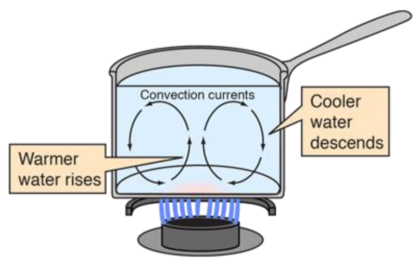


Figure 3. Heat by Convection. Nave, R. (2020). Heat Transfer (image). HyperphysicsThermodynamics. Retrieved from http://hyperphysics.phyastr.gsu.edu/hbase/thermo/heatra.html

Convection is heat transfer by mass motion of a fluid such as air or water when the heated fluid is caused to move away from the source of heat, carrying energy with it. Convection above a hot surface occurs because hot air expands, becomes less dense, and rises. Hot water is likewise less dense than cold water and rises, causing convection currents which transport energy.

Example. Water boiling in a pan, the atmosphere, the earth's surface is warmed by the sun, the warm air rises and cool air moves in.

Heat by Radiation

Radiation is a method of heat transfer that does not rely upon any contact between the heat source and the heated object as is the case with conduction and convection. Heat can be transmitted through empty space by thermal radiation often called infrared radiation. This is a type electromagnetic radiation. No mass is exchanged and no medium is required in the process of radiation.

Examples of radiation is the heat from the sun, or heat released from the filament of a light bulb.

When a high temperature body is brought into contact with a low temperature body, the temperatures equilibrate: there is heat flow from higher to lower temperature, until the temperatures of the bodies are equivalent. The high temperature body loses thermal energy, and the low temperature body acquires this same amount of thermal energy. The system is then said to be at thermal equilibrium.

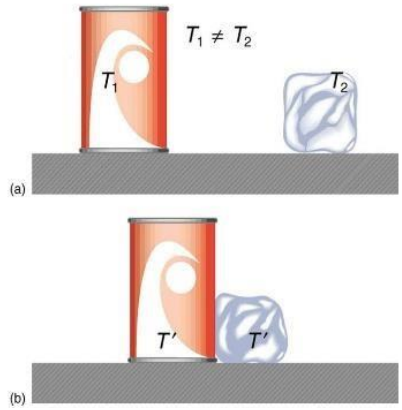


Figure 4. Heat Transfer. Heat and Heat Transfer Methods (image). Lumen Learning. Retrieved from https://courses.lumenlearning.com/physics/chapter/14-1-heat/

In figure (a) the soft drink and the ice have different temperatures, T_1 and T_2, and are not in thermal equilibrium. In figure (b), when the soft drink and ice are allowed to interact, energy is transferred until they reach the same temperature T', achieving equilibrium. Heat transfer occurs due to the difference in temperatures. In fact, since the soft drink and ice are both in contact with the surrounding air and bench, the equilibrium temperature will be the same for both.

The can of cola and ice cube start at different temperatures. When they come into contact, heat is transferred from the cola can to the ice cube until both bodies reach thermal equilibrium. If two objects are in thermal equilibrium, they are at the same temperature.

Work

- Is the second form of energy transfer
- Is the transfer of energy accomplished by a force moving a mass some distance against resistance.

Ex. Lifting a set of rollercoaster cars up a hill against the pull of gravity.

The most common type of work in chemical processes is pressure-volume work (P-V work).

When a gas expands, it can do work. If an inflated balloon is released before it is tied off, it flies around as the gas inside the balloon expands into the large volume of the room. Because the flying balloon has mass, it is easy to see that the expanding gas is doing work on the balloon: this is pressure-volume work.

Pressure-Volume Work: Work done by a gas

Gases can do work through expansion or compression against a constant external pressure. Work done by gases is also sometimes called PressureVolume or PV work

A gas in a piston

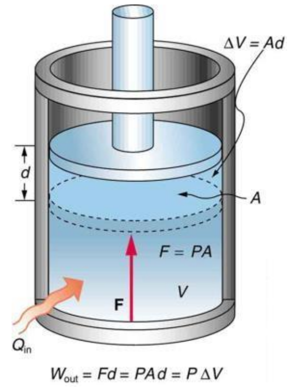


Figure 5. Expanding gas in a piston. Coker, R. The First Law of Thermodynamics (image). Retrieved from https://web2.ph.utexas.edu/~coker2/index.files/chapter18.htm

If the gas is heated, energy is added to the gas molecules. Observe the increase in average kinetic energy of the molecules by measuring how the temperature of the gas increases. As the gas molecules move faster, they also collide with the piston more often. These increasingly frequent collisions transfer energy to the piston and move it against an external pressure, increasing the overall volume of the gas. In this example, the gas has done work on the surroundings, which includes the piston and the rest of the universe.

To calculate how much work a gas has done or (has done to it) against a constant external pressure:

$\boldsymbol{Work = W = -P_{external}\Delta V}$ where $P_{external}$, is the external pressure (as opposed to the pressure of a gas in the system) and ΔV is the change in the volume of the gas, which can be calculated from the initial and final volume of the gas:

$$\Delta \boldsymbol{V = V_{final} - V_{initial}}$$

Assuming that the gases are ideal the equation

$$\boldsymbol{W = P\Delta V = nRT}$$

Energy Units

SI unit of energy: Joules (J)

$$\boldsymbol{1J = 1\ kg\ \frac{m^2}{s^2}}$$

British Thermal Unit (BTU)- the amount of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

Calorie (C) – the amount of energy required to heat 1 g of water from 14.5 ℃ to 15.5 ℃

$$1\ cal = 4.184\ J$$

$$1\ kcal = 4184\ J$$

$$1 Btu = 1055\ J$$

Conservation of Energy

The constraint on the energy transformation is that total energy must be conserved.

If we account properly for all the energy conversion and energy transfer processes, the total amount of energy present must remain constant.

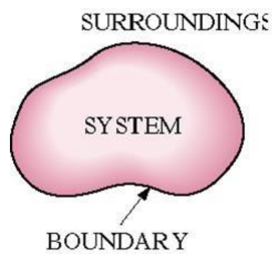
Definition of Terms

A "***system***" is the part of the universe that is being considered.

The "***surroundings***" are everything else in the environment or the remainder of the universe.

System + Surroundings = Universe

The system and surroundings are separated by a "boundary" can either insulate or allow heat flow.



OPEN SYSTEM: Mass and energy freely moves in and out between the system and the surrounding

CLOSED SYSTEM: when matter CANNOT cross the boundary

ISOLATED SYSTEM: No interaction between the system and the surrounding

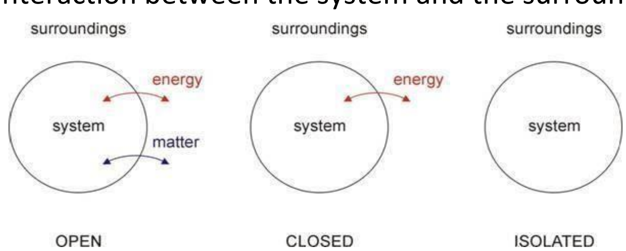


Figure 6. Open, closed and isolated thermodynamic systems. L. Lauhon, K. R. Shull

(2020).Thermodynamics of Materials (image). Retrieved from http://msecore.northwestern.edu/314/314text.xhtml

Relationship between HEAT and WORK

The overall change in energy, E, of a system can be written as

$$\Delta E = q + W$$

where q is the heat and W is the work. The symbol Δ (delta) meaning "the change in" defined as the difference between the final and the initial state

$$\Delta E = E_{final} - E_{initial}$$

Signs for the quantities of heat and work

- q is positive if heat flows INTO a system from the surroundings
- q is negative if heat flows OUT of a system on the surroundings
- w is positive when work is done ON the system
- w is negative when work is done BY the system

Energy transferred INTO a system is a positive sign and energy flowing OUT of a system is negative sign.

Example 1. If 515 J of heat is added to a gas that does 218 J of work as a result, what is the change in the energy of the system. Solution:

Work is done by the system, w = - 218 J

Heat is added to the system, q = +515 J

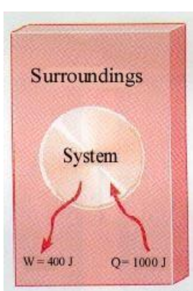
$\Delta E = q + w$

$= +515 + (-218)$

$\Delta E = 297$ J

Example 2. 1000 J of thermal energy flows into a system. At the same time, 400 J of work is done by the system. What is the change in the system's internal energy?

Solution:

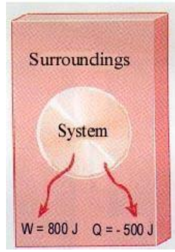


$\Delta E = q + w$

$= 1000 \text{ J} + (-400 \text{ J})$

$= 600$ J

Example 3. 800 J of work is done on a system as 500 J of thermal energy is removed from the system. What is the change in the system's internal energy? Solution:



$\Delta E = q + w$

$= -500\text{ J} + 800\text{ J}$

$= -500\text{ J} + 800\text{ J} = 300\text{ J}$

Heat Capacity

The specific heat capacity of a substance is the amount of energy needed to change the temperature of 1kg of the substance by 1℃

Specific Heat Capacity can be thought of as a measure of how much heat energy is needed to warm the substance up.

You will possibly have noticed that it is easier to warm up a saucepan full of oil than it is to warm up one full of water.

The table below shows how much energy it takes to heat up some different substances.

The small values show that not a lot of energy is needed to produce a temperature change, whereas the large values indicate a lot more energy is needed.

What is the importance of water having high heat capacity?

The high heat capacity of water has a great deal to do with regulating extremes in the environment. For instance, our fish in the pond is indeed happy because the heat capacity of the water in her pond above means the temperature of the water will stay relatively the same from day to night.

The oceans play a large role in climate at both a regional and global scale because water has an ability to resist sudden changes in temperature. Because of this, water is said to have a high specific heat. Because of the high specific heat of water, the ocean and other bodies of water warm much slower when the sun shines on them than nearby rocks, soil, and buildings.

Because water absorbs and releases heat at a rate much slower than land, air temperatures in areas near large bodies of water tend to have smaller fluctuations. The high specific heat of water, and the mixing that occurs as a result of wind interaction with water, help to moderate the temperature of land located near an ocean.

In the desert, daily temperature variations are extreme. It can be very hot during the day and very cold at night. This is because deserts, by definition, lack large amounts of liquid water.

Specific heat is the physical property of a material that measures how much heat is required to raise the temperature of 1 gram of that material by 1 deg C (or Kelvin).

q = mCΔT

where

q = quantity of heat

m = mass

C = specific heat capacity

ΔT = change in temperature

Unit: $\frac{J}{g\,K}$ or $\frac{J}{g\ ℃}$

Molar Heat Capacity is a physical property that describes how much heat is required to raise the temperature of 1 mole of a substance by 1 deg C. ***q = nCp□T*** where : q = quantity of heat

n = no. of moles

Cp = heat capacity at constant pressure □*T* = change in temperature

Unit: $\frac{J}{mole\,K}$ or $\frac{J}{mole\ ℃}$

Example 1. How much energy would be needed to heat 450 grams of copper metal from a temperature of 25.0 ˚C to a temperature of 75.0 ˚C? The specific heat of copper at 25.0C is 0.385 J/g ˚C Solution:

Change in temperature (*ΔT)* is: *ΔT* =75 ˚*C – 25* ˚*C = 50* ˚*C*

q = m x C x ΔT

$$q = (450\ g) \times (0.385\ J/g\ ^\circ C) \times (50.0\ ^\circ C)$$

$$q = 8662.5\ J$$

Example 2. Heating a 24.0 g aluminum can raises its temperature by 15.0 ˚C.

Find the value of q for the can.

Solution:

The value of the specific heat of aluminum can is 0.900 J g^{-1}□C^{-1}

$q = mC\Delta T$

$$q = 24.0\ g \times 0.900\ J/g\ ^\circ C \times 15.0\ ^\circ C$$

$$q = 324\ J$$

Example 3. A block of iron weighing 207 g absorbs 1.50 kJ of heat. What is the change in the temperature of the iron?

Solution:

q = 1.50 kJ m=207 g C= 0.500 $\frac{J}{g\ ^\circ C}$

$$q = mC\Delta T$$

$$\Delta T = \frac{q}{mC}$$

$$\Delta T = \frac{1500\ J}{207\ g \times 0.500\ \frac{J}{g\ ^\circ C}}$$

$$\Delta T = 14.493\ ^\circ C$$

Example 4. The molar heat capacity of liquid water is 75.3 J/ mol K. If 37.5 g of water is cooled from 42.0 to 7.0 ˚C, what is q for the water?

Solution:

Because water is cooling, ΔT will be negative

$$\Delta T = 7\ ^\circ C - 42\ ^\circ C = -35\ ^\circ C$$

Converting mass of 37.5 g to mole

Molecular weight of water = 18.02 g/mol (based on the sum of atomic weights in the periodic table)

$$37.5\ g\ x\ \frac{1\ mol}{18.02\ g} = 2.081\ mol$$

Solving for q,

q = n Cp ΔT

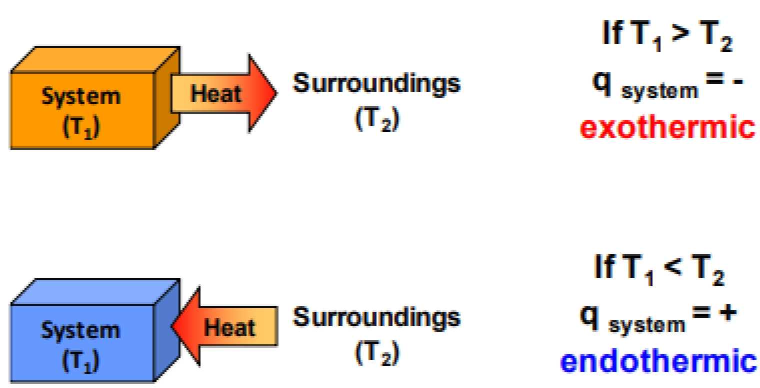
= 37.5 g x 2.081 mol x 75.3 J/mol K x -35 ˚C

= -5484.531 J or -5.48 kJ

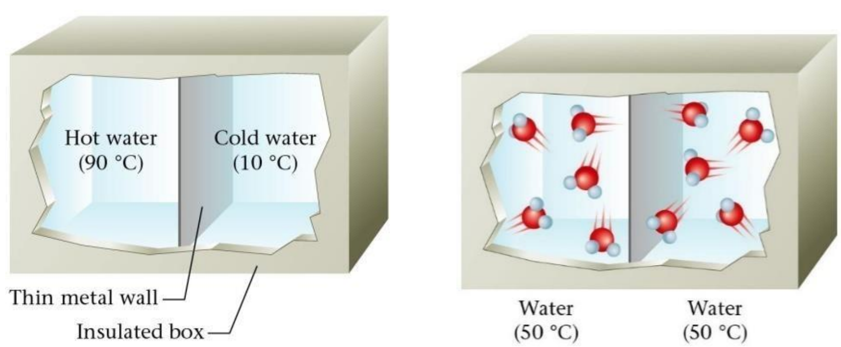
Note: The negative value indicates that the system has lost energy to the surroundings.

Heat (q)

- the transfer of energy between objects due to a temperature difference.
- Flows from higher-temperature object to lower-temperature object



What will happen over time?



When you put two objects of different temperatures in contact with one another, the faster-moving molecules in one material will collide with the slower-moving molecules in the other. The heat energy will gradually spread out until the two objects have the same temperature - until they have reached thermal equilibrium.

Calorimetry

- is the term used to describe the measurement of heat flow.
- Experiments are carried out in devices called calorimeters.

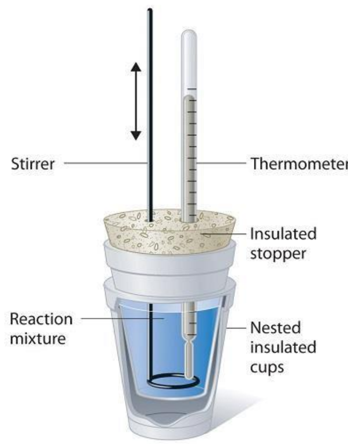


Figure 7. Coffee Cup Calorimeter. This simplified version of a constant-pressure calorimeter consists of two Styrofoam cups nested and sealed with an insulated stopper to thermally isolate the system (the solution being studied) from the surroundings (the air and the laboratory bench). Two holes in the stopper allow the use of a thermometer to measure the temperature and a stirrer to mix the reactants. ChemistryLibretexts (2019). Heats of Reactions and Calorimetry (image). Retrieved from https://chem.libretexts.org/Courses/University_of_British_Columbia/UBC_CHEM_154%3A_Chemistry_for_Engineering/07%3A_Energy_and_Chemistry/7.3%3A_Heats_of_Reactions_and_Calorimetry

Much calorimetry is carried out using a coffee-cup calorimeter, under constant pressure (i.e. atmospheric pressure). If we assume that no heat is lost to the surroundings, then the energy absorbed inside the calorimeter must be equal to the energy released inside the calorimeter.

$$q_{absorbed} = q_{released}$$

A Bomb Calorimeter

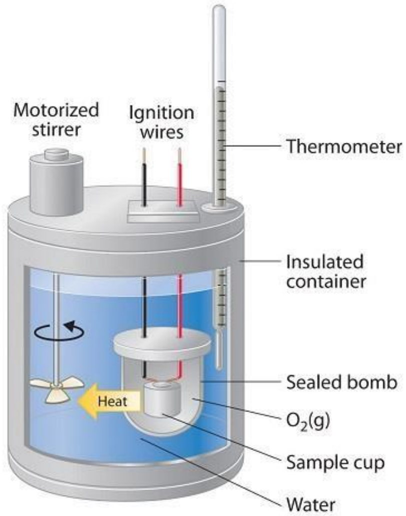


Figure 8. A Bomb Calorimeter. After the temperature of the water in the insulated container has reached a constant value, the combustion reaction is initiated by passing an electric current through a wire embedded in the sample. Because this calorimeter operates at constant volume, the heat released is not precisely the same as the enthalpy change for the reaction. ChemistryLibretexts (2019). Heats of Reactions and Calorimetry (image). Retrieved from https://chem.libretexts.org/Courses/University_of_British_Columbia/UBC_CHEM_154%3A_Chemistry_for_Engineering/07%3A_Energy_and_Chemistry/7.3%3A_Heats_of_Reactions_and_Calorimetry

Is a fairly complicated piece of equipment. But the general premise of the device is simply to carry out a reaction at constant volume and with no heat flow between the calorimeter and the outside world.

Example 1. A glass contains 250.0 g of warm water at 78.0 ˚C. A piece of gold at

2.30 ˚C is placed in the water. The final temperature reached by this system is 76.9 ˚C. What was the mass of gold? The specific heat of water is 4.184 J/ g ˚C, and that of gold is 0.129 J/ g ˚C.

Solution: Assume that heat flows only between the gold and water, with no heat lost to or gained from the glass or the surroundings.

$$\boldsymbol{q_{gold} = -q_{water}}$$

$$(mC\Delta T)_{gold} = -(mC\Delta T)_{water}$$

$$\Delta T = T_{final} - T_{initial}$$

ΔTgold = 76.9 ˚C – 2.30 ˚C

ΔTgold = 74.6 ˚C

ΔTwater = 76.9 ˚C – 78.0 ˚C
ΔTwater = -1.1 ˚C
Substitute the values,

$$(mC\Delta T)_{gold} = -(mC\Delta T)_{water}$$

$$m_{gold}\ x\ 0.129\ \frac{J}{g\ °C}\ x\ 74.6\ °C = -250.0\ g\ x\ 4.184\ \frac{J}{g\ °C}\ x\ (-1.1°C)$$

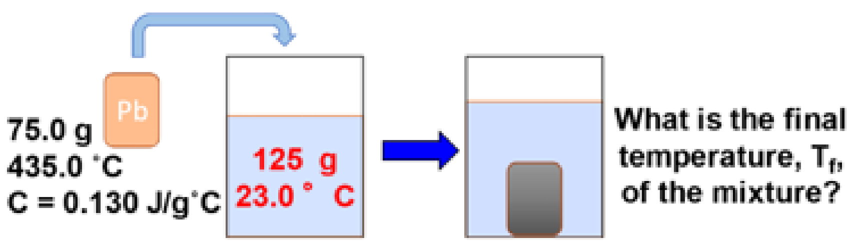
Simplify

$$m_{gold} = \frac{-250.0\ g\ x\ 4.184\ \frac{J}{g\ °C}\ x\ (-1.1°C)}{0.129\ \frac{J}{g\ °C}\ x\ 74.6\ °C}$$

$$m_{gold} = 119.563\ g$$

Example 2. A 75.0 g piece of lead (specific heat = 0.130 J/g °C), initially at 435 °C, is set into 125.0 g of water, initially at 23.0 °C. What is the final temperature of the mixture?

Solution:



$$q_{water} = -q_{Pb}$$

q = m x C x ΔT for both cases, although specific values differ

Plug in known information for each side and Solve for T_f.

$$m_{water}\ C_{water}\ \Delta T_{water} = -m_{Pb}\ C_{Pb}\ \Delta T_{Pb}$$

$$125.0\ (4.184)\ (T_f - 23) = -75\ (0.13)\ (T_f - 435)$$

$$523\ T_f - 12029 = -9.75\ T_f + 4241.25$$

$$523\ T_f + 9.75\ T_f = 4241.25 + 12029$$

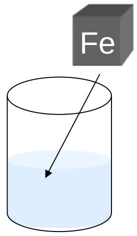
$$532.75T_f = 16270.25$$

$$T_f = \frac{16270.25}{532.75}$$

$$\mathbf{T_f = 30.540\ ˚C}$$

Example 3. A 240.0 g of water (initially at 20.0 °C) are mixed with an unknown mass of iron initially at 500.0°C (C_{Fe} = 0.4495 J/g°C). When thermal equilibrium is reached, the mixture has a temperature of 42.0 ℃. Find the mass of the iron.

Solution:



T = 500°C mass = ? grams

T = 20°C mass = 240 g

heat LOST by iron = heat GAIN water

$$-q_{Fe} = q_{H_2O}$$

$$-[(\text{mass})(C_{Fe})(\Delta T)]_{Fe} = [(\text{mass})(C_{H_2O})(\Delta T)]_{H_2O}$$

$$-[(m_{Fe})(0.4495)(42 - 500)] = (240.0)(4.184)(42 - 20)]$$

$$-[(m_{Fe})(0.4495)(458)] = (240.0)(4.184)(22)$$

$205.871\ m_{Fe} = \quad 22091.52\ m_{Fe} =$

$\underline{22091.52}$

205.871

$m_{Fe} = 107.308$ g