PROJECT LEAD THE WAY

PLTW

Igniting imagination and innovation through learning.

Introduction to Thermodynamics

Thermodynamics

Rub your hands together for 15 seconds.

Are your hands warm?

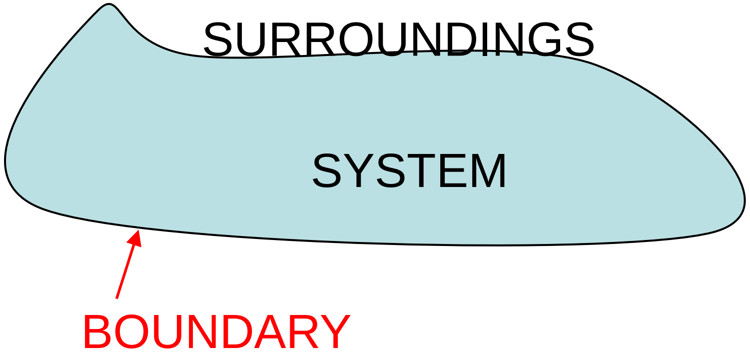
Thermal energy

Thermodynamics

The study of the effects of work, heat flow, and energy on a system

Movement of thermal energy

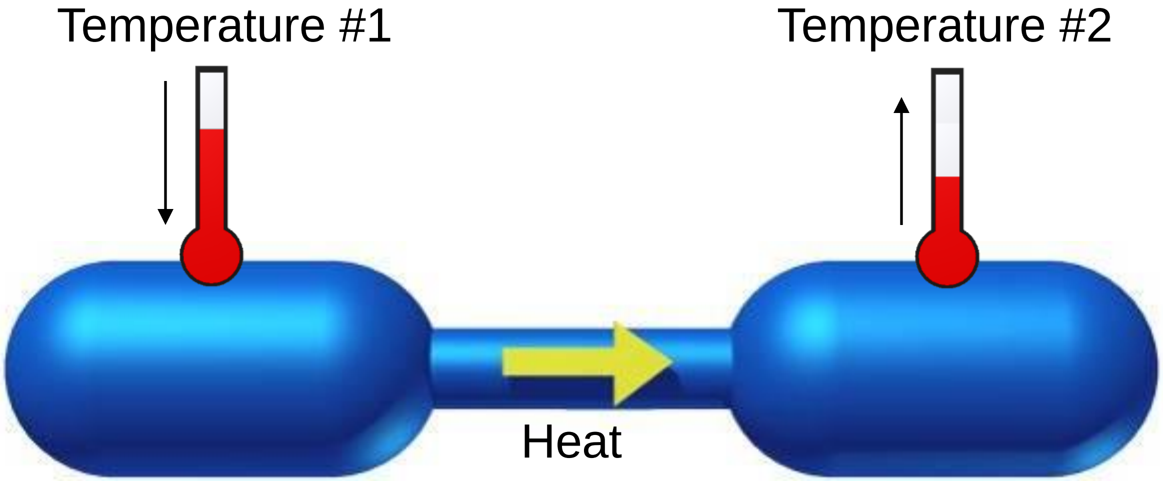
Engineers use thermodynamics in systems ranging from nuclear power plants to electrical components.



Thermal Energy versus Temperature

Thermal Energy is kinetic energy in transit from one object to another due to temperature difference. (Joules)

Temperature is the average kinetic energy of particles in an object – not the total amount of kinetic energy particles. (Degrees)



Temperature Scales

Scale	Freezing point of water	Boiling point of water
Celsius	0°C	100°C
Fahrenheit	32°F	212°F
Kelvin	273K	373K

Matter is made up of molecules in motion (kinetic energy)

An increase in temperature increases motion

A decrease in temperature decreases motion

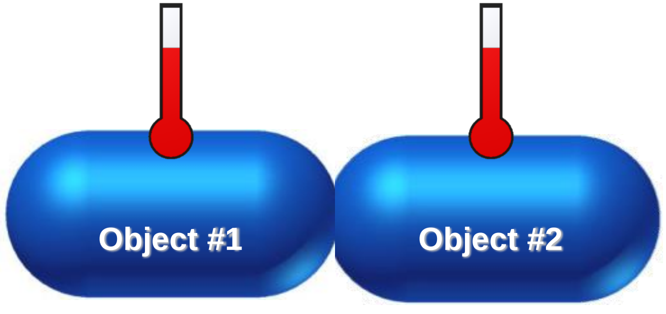
Absolute Zero occurs when all kinetic energy is removed from a object 0 K = -273° C

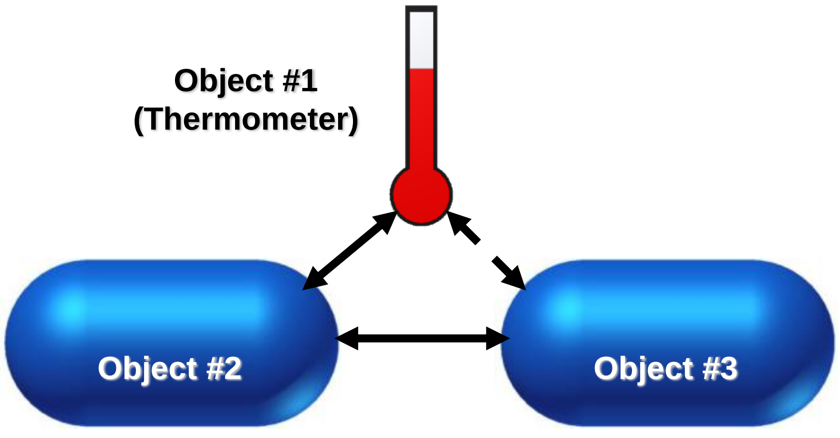
Thermodynamic Equilibrium

Thermal equilibrium is obtained when touching objects within a system reach the same temperature.

When thermal equilibrium is reached, the system loses its ability to do work.

Zeroth Law of Thermodynamics: If two systems are separately found to be in thermal equilibrium with a third system, the first two systems are in thermal equilibrium with each other.





Thermal Energy (heat) Transfer

The transfer or movement of thermal energy

Most common types of transfer

- Convection
- Conduction
- Radiation

100% efficiency is unattainable

ALL processes are irreversible

1st Law of Thermodynamics

Law of energy conservation applied to a thermal system

- Thermal energy can change form and location, but it cannot be created or destroyed.
- Thermal energy can be increased within a system by adding thermal energy (heat) or by performing work in a system.




1st Law of Thermodynamics

Example: Using a bicycle pump

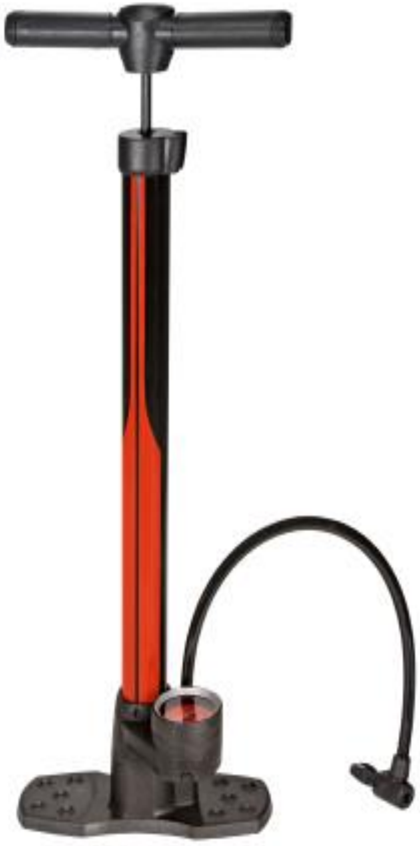
Pumping the handle results in what?

– Applying mechanical energy into the system

– Mechanical energy is converted into thermal energy through friction (the pump becomes hot)

The total increase in internal energy of the system is equal to what?

– The applied mechanical energy



2nd Law of Thermodynamics

Thermal energy flows from hot to cold

When you touch a frozen pizza with your hand, thermal energy flows in what direction?

Hand → Pizza

When you touch a cooked pizza with your hand, thermal energy flows in what direction?

Pizza → Hand

2nd Law of Thermodynamics

Entropy is the measure of how evenly distributed heat is within a system.

- A system tends to go from order to disorder

Firewood has low entropy (molecules in order) when stacked and high entropy when burning (molecules in disorder).

The total amount of energy in the world does not change, but the availability of that energy constantly decreases.

Thermal Energy Transfer

Convection

The transfer of thermal energy by movement of fluid (liquid or gas)

When fluid is heated, it expands, becomes less dense, and rises.

Boiler heating systems circulate heat throughout a home without pumps through the use of convection.

Thermal Energy Transfer

Conduction

The transfer of thermal energy within an object or between objects from molecule to molecule

A metal spoon placed in a hot cup of soup will feel warm to your hand. The heat from the soup is conducted through the spoon.

Thermal Energy Transfer Equations

$$Q = m \bullet C_p \bullet \Delta T$$

Q = energy transfer (Joules)

m = mass of the material (kilograms)

C_p = specific heat capacity of the material ($J / kg^{\circ}C$)

T = temperature

Δ = difference

Thermal Energy Transfer Equations

$$P = \frac{Q}{\Delta t} \qquad P = kA\frac{\Delta T}{L} \qquad k = \frac{PL}{A\Delta T}$$

P = rate of energy transfer (Watts)

Q = energy transfer (Joules)

t = time (seconds)

k = thermal conductivity

A = area of thermal conductivity

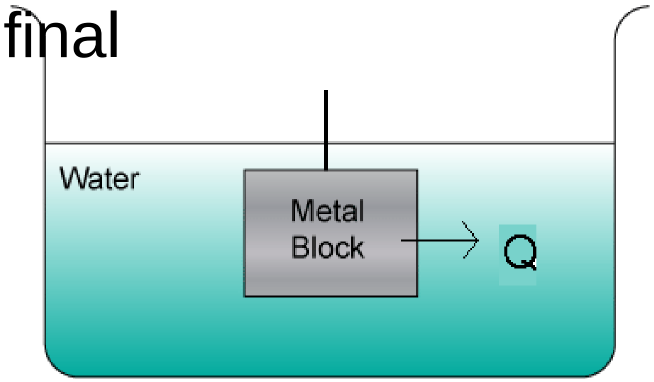
L = thickness of material

T = temperature

Δ = difference

Calculating Energy Transfer

Calculate the energy transferred when a block of aluminum at 80.0°C is placed in 1.00 liter (1kg) of water at 25.0°C if the final temperature becomes 30.0°C.



Step 1. List all known values

Mass of water = 1 kg

C_p of water = 4184 $\frac{J}{kg \times ^{o} C}$

Difference in temperature = ΔT = 30.0°C – 25.0°C = 5.0°C

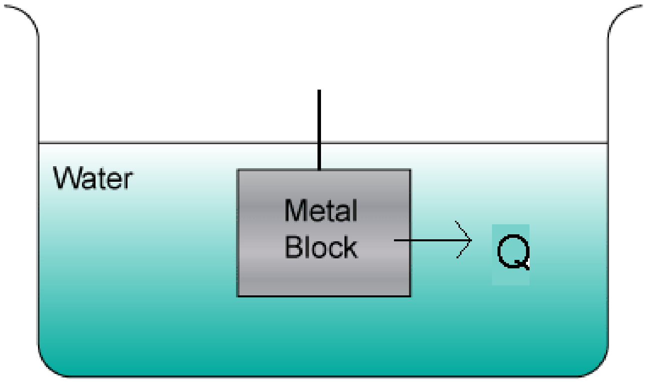
C_p of Al = 900. $\frac{J}{kg \times ^{o} C}$

Difference in temperature = ΔT = 80.0°C – 30.0°C = 50.0°C

Calculating Energy Transfer

Step 2. List all unknown values

Q = energy transferred
m_{Al} = mass of the Al block



Step 3. Select equations to solve unknown values

$$Q = m \bullet C_p \bullet \Delta T \quad Q_{Al} = Q_{water}$$

Step 4. Solve for Q_{water}

$$Q_{water} = (1.00\text{kg}) \bullet 4184 \frac{\text{J}}{\text{kg} \times {}^{o}\text{C}} \bullet 5.0^{o}\text{C} = 21,000 \text{ J gained}$$

Calculating Energy Transfer

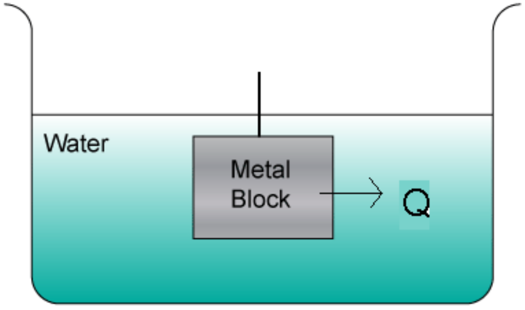
Step 5. Solve for m_{Al}

$$Q_{Al}\,(\text{lost}) = Q_{water}\,(\text{gained}) = 20,\underline{920}\ \text{J}$$

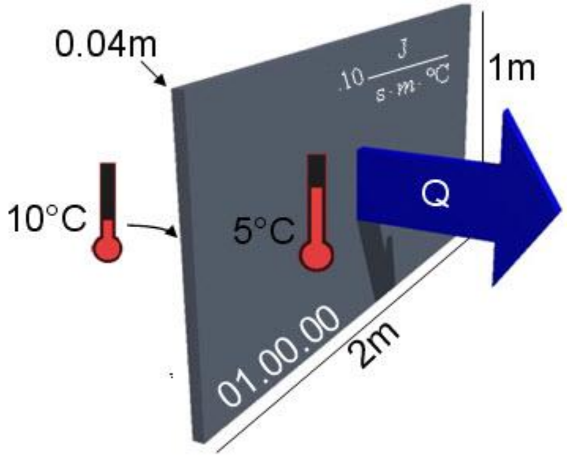
$$Q_{Al} = m_{Al} \bullet Cp \bullet \Delta T$$

$$m_{Al} = \frac{Q_{Al}}{C_p \bullet \Delta T} = \frac{20,\underline{920}\,\text{J}}{900.\,\frac{\text{J}}{\text{kg}^\circ\text{C}} \bullet 50.0^\circ\text{C}}$$

$$m_{Al} = 0.46\ \text{kg} = 460\text{g}$$



Calculating Energy Transfer



Calculate the energy transfer in a wall section measuring 2m by 1m by 0.04m thick with a thermal conductivity of 0.10 $\frac{J}{s \times m \times °C}$. Opposing sides of the wall section have a temperature of 10°C and 5°C after one hour.

Step 1. List all known values

Area of thermal conductivity = $A = 2m * 1m = 2m^2$

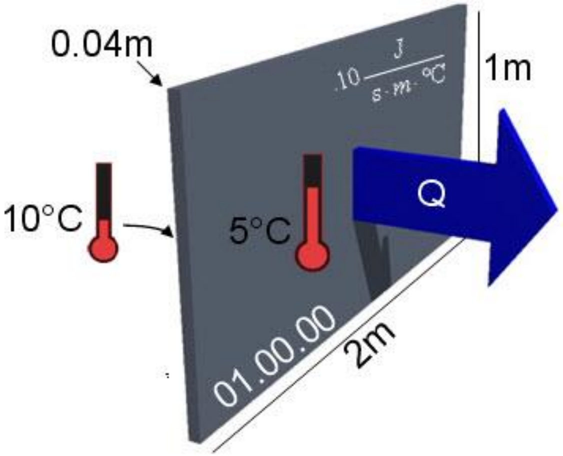
Thermal conductivity = $k = 0.10 \frac{J}{s \times m \times ^{o}C}$

Thickness of material = $L = 0.04m$

Difference in temperature = $\Delta T = 10°C - 5°C = 5°C$

Difference in time = $\Delta t = 1 \text{ hour} = 3600s$

Calculating Energy Transfer



Step 2. List all unknown values

P = Rate of energy transfer
Q = Energy transfer

Step 3. Select equations to solve unknown values

$$P = \frac{Q}{\Delta t} \qquad P = kA\frac{\Delta T}{L}$$

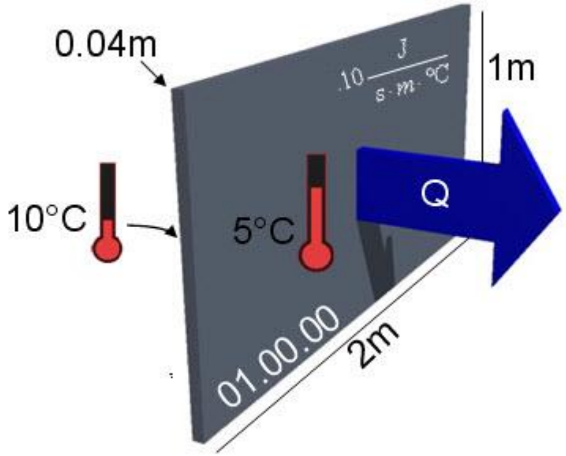
Step 4. Solve in terms of Q

$$Q = P \bullet \Delta t$$

Step 5. Combine equations

$$Q = (kA\frac{\Delta T}{L}) \bullet \Delta t$$

Calculating Energy Transfer



Step 6. Apply known values

$$Q = (kA\frac{\Delta T}{L}) \bullet \Delta t$$

$$Q = \left(\left(0.10\frac{J}{s \times m \times {}^{\circ}C} \bullet 2m^2\right) \bullet \left(\frac{5^{\circ}C}{0.04m}\right)\right) \bullet 3600s$$

$$Q = 90,000J$$

U-Value

Thermal Conductivity of a Material

Overall heat coefficient

The measure of a material's ability to conduct heat

****measure how good of an <u>insulator</u> a material is.**

****The LOWER the U value, the BETTER a material is at being an insulator.**

$$U = \frac{P}{A\Delta T}$$

Metric system $\frac{\text{W}}{(\text{m}^2)(°\text{C})}$

U.S. customary system $\frac{\text{Btu}}{(\text{ft}^2)(\text{hr})(°\text{F})}$

R-Value

Thermal Resistance of a Material

How well the object retains the heat=insulating

The higher the R-value, the higher the resistance (better insulation!!)

$$R = \frac{1}{U} \qquad U = \frac{P}{A\Delta T}$$

Bulk R-value =
R-value $_{\text{Object 1}}$ + R-value $_{\text{Object 2}}$ + … = Total R-Value

Thermal Energy Transfer

Radiation

The process by which energy is transmitted through a medium, including empty space, as electromagnetic waves

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Electromagnetic waves transfer to food and other matter

Stefan's Law

All objects lose and gain thermal energy by electromagnetic radiation.

$$P_{net} = \sigma A e(T_2^{\ 4} - T_1^{\ 4})$$

P = radiated energy transfer

σ = Stefan's constant = $5.6696 \times 10^{-8} \dfrac{W}{m^2 \cdot K^4}$

A = area

e = emissivity constant

T = temperature in Kelvin

Thermal Energy Transfer

Prior to dressing for school, a student watches the morning weather to decide what clothes to wear. The bedroom is 65ºF and the student's skin is 91.4ºF. Determine the net energy transfer from the student's body during the 15.0 minutes spent watching the morning weather. **Note:** Skin emissivity is 0.90, and the surface area of the student is 1.30m².

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Step 1. List all known values

Area $= A = 1.30 m^2$

Emissivity constant $= e = 0.90$

Stefan's constant $= \sigma = 5.6696 \cdot 10^{-8} \frac{W}{m^2 \times K^4}$

Bedroom temperature $= T_1 = 65°F$

Skin temperature $= T_2 = 91.4°F$

Time in seconds $= t = 15.0$ minutes $= 900.s$

Thermal Energy Transfer

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Step 2. List all unknown values

P = Rate of energy transfer
Q = Energy transfer

Step 3. Select equations to solve unknown values

$$P_{net} = \sigma A e (T_2^4 - T_1^4) \qquad Q = P \bullet \Delta t$$

Step 4. Apply known values to $P_{net} = \sigma A e (T_2^4 - T_1^4)$

$$\text{Solve for } (T_2^4 - T_1^4)$$

$$91.4°F = 306.15K$$

$$65°F = 291.48K$$

$$(T_2^4 - T_1^4) = (8{,}784{,}904{,}710.59K) - (7{,}218{,}301{,}921.12K)$$

$$(T_2^4 - T_1^4) = 1566602759.47K$$

Thermal Energy Transfer

Step 4 (continued). Apply known values to $P_{net} = \sigma Ae\left(T_2^{\,4} - T_1^{\,4}\right)$

$$P_{net} = \left(5.6696\times10^{-8}\ \frac{W}{m^2 \times K^4}\right)\times\left(1.30m^2\right)\times\left(0.90\right)\times\left(1,566,602,759.47K\right)$$

$$P_{net} = 103.\underline{92}W$$

Step 5. Combine equations and solve

$$Q = P\Delta t$$

$$Q = 103.\underline{92}W \times 900.s$$

$$Q = 93,500J$$

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93,500J of energy are transferred from the student's body during the 15 minutes spent watching the morning weather.

Applications of Thermal Energy

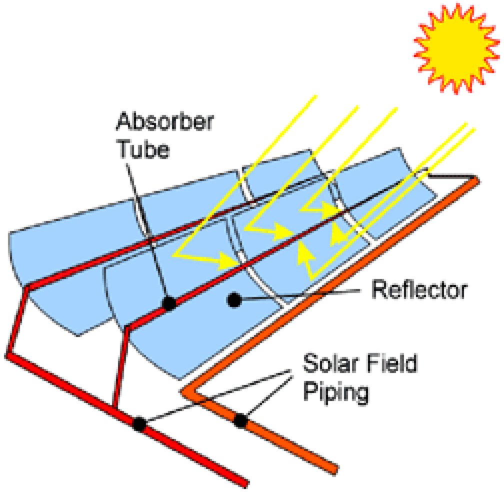

Figure 1. A solar collector assembly

http://www.nrel.gov

Examples of Solar Energy

All images were obtained from the following URL: http://www1.eere.energy.gov

Geothermal Energy

Energy generated from the thermal energy stored beneath the Earth's surface

Also refers to the heat that is collected from the atmosphere; for instance, near the oceans