Thermal Energy

- Heat and Temperature are not the same!!
- Cold is the absence of heat, not an energy
  - Same concept as light/dark
- Cold "can't come in", heat flows out
  - Heat flows from High Temp → Low Temp

Temp vs. Heat

Temperature – The measurement of the average kinetic energy of the particles in an object.

Heat – A form of energy, measured in Joules (J).

Adding heat to an object will either:

1. Raise the object's temperature
2. Cause a change in state (solid→liquid→gas)

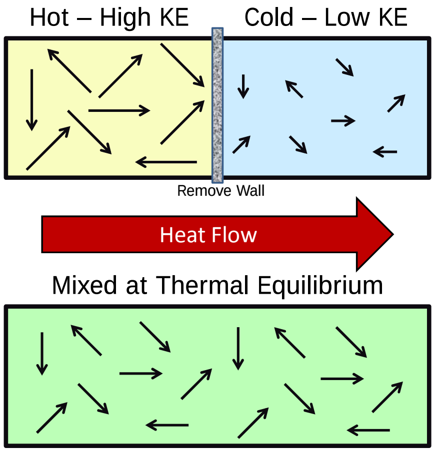
Temp vs. Heat

High Temperature → Particles move fast

Low Temperature → Particles move slow

When a hot system meets a cold system…
Hot system transfers heat until even temp.

Thermal Equilibrium – Objects have equal temp, average KE, and energy flow rate



Common Temperature Scales

Celsius – related to Centigrade (100 degree)
0°C – water freezes
100°C – water boils

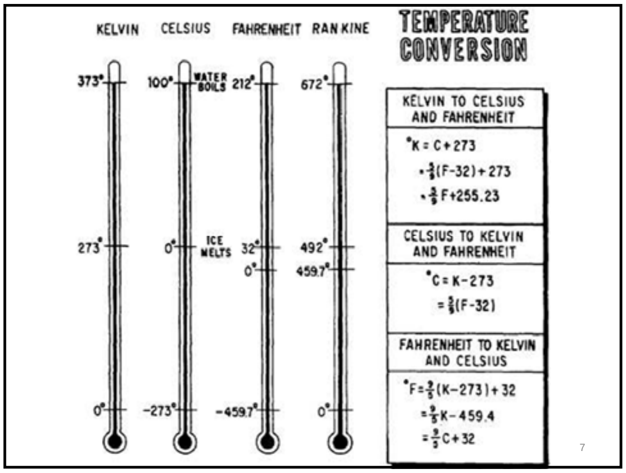
Fahrenheit – used in USA and Belize
32°F – water freezes
212°F – water boils

To make the degree symbol ° type Alt + 0176

Absolute Temperature Scales

Kelvin – related to Celsius, starts at "absolute 0" as lowest impossible value to reach.
0K – all motion stops
273.15K – water freezes
DO NOT USE ° SYMBOL!

Rankine – the "Fahrenheit version of Kelvin"
0°R – Absolute lowest Temp
459.67°R – water freezes



TEMPERATURE CONVERSION

KELVIN TO CELSIUS AND FAHRENHEIT

$°K = C + 273$

$= \frac{5}{9}(F-32) + 273$

$= \frac{5}{9}F + 255.23$

CELSIUS TO KELVIN AND FAHRENHEIT

$°C = K - 273$

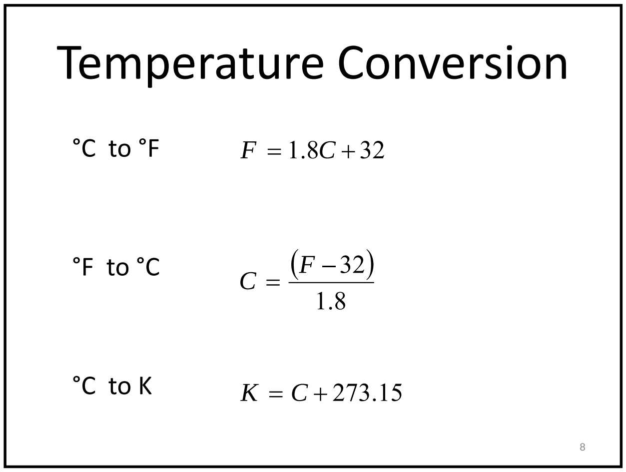
$= \frac{5}{9}(F-32)$

FAHRENHEIT TO KELVIN AND CELSIUS

$°F = \frac{9}{5}(K-273) + 32$

$= \frac{9}{5}K - 459.4$

$= \frac{9}{5}C + 32$



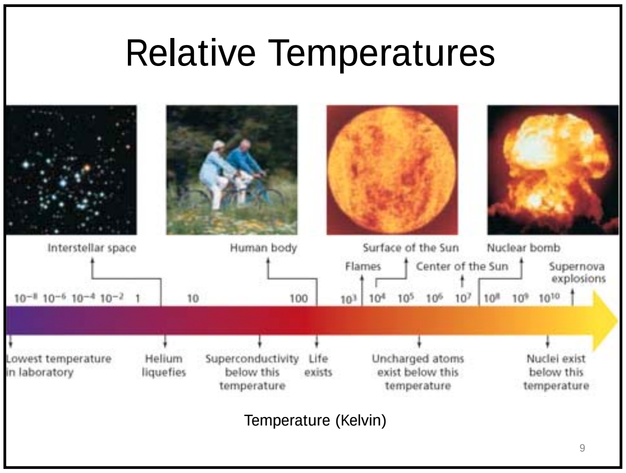
Temperature Conversion

°C to °F $F = 1.8C + 32$

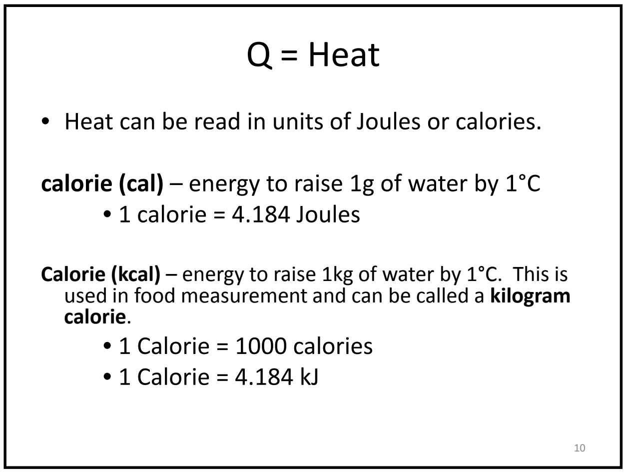
°F to °C $C = \dfrac{(F-32)}{1.8}$

°C to K $K = C + 273.15$

Relative Temperatures



Temperature (Kelvin)

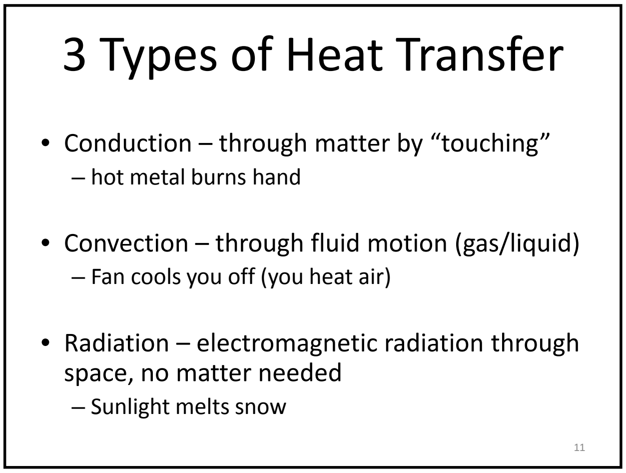


Q = Heat

- Heat can be read in units of Joules or calories.

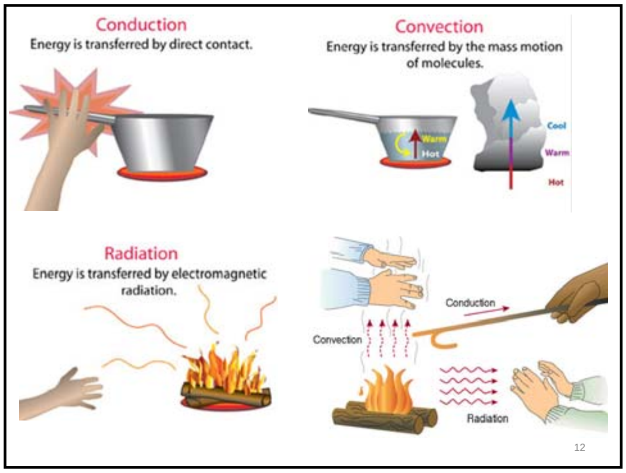
calorie (cal) – energy to raise 1g of water by 1°C
  - 1 calorie = 4.184 Joules

Calorie (kcal) – energy to raise 1kg of water by 1°C. This is used in food measurement and can be called a **kilogram calorie**.
  - 1 Calorie = 1000 calories
  - 1 Calorie = 4.184 kJ



3 Types of Heat Transfer

- Conduction – through matter by “touching”
  - hot metal burns hand
- Convection – through fluid motion (gas/liquid)
  - Fan cools you off (you heat air)
- Radiation – electromagnetic radiation through space, no matter needed
  - Sunlight melts snow



Conduction
Energy is transferred by direct contact.

Convection
Energy is transferred by the mass motion of molecules.

Radiation
Energy is transferred by electromagnetic radiation.

Heat Transfer

$$Q = m\,C_p\,(T_f – T_o)$$

Q – Heat
m – mass
T – temperature in Kelvin
C_p – specific heat
$\Delta T = (T_f – T_o)$

Way to remember: “m c delta T”

Specific Heat

- The amount of energy needed to raise one gram of a substance one degree Celsius.
- Units are [J/kg·K]
- Higher values → “stores” a lot of energy, takes large energy change to heat or cool

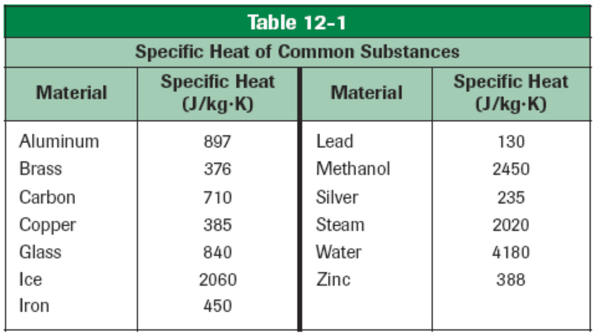


Table 12-1

Specific Heat of Common Substances

Material	Specific Heat (J/kg·K)	Material	Specific Heat (J/kg·K)
Aluminum	897	Lead	130
Brass	376	Methanol	2450
Carbon	710	Silver	235
Copper	385	Steam	2020
Glass	840	Water	4180
Ice	2060	Zinc	388
Iron	450		

Conservation of Energy

In a closed system with two objects:

$$\Delta\ E_A\ -\ \Delta E_B\ = 0 \quad \rightarrow \quad \Delta E_A\ =\ -\ \Delta E_B$$

$$\Delta E = Q = m\ C\ \Delta T$$

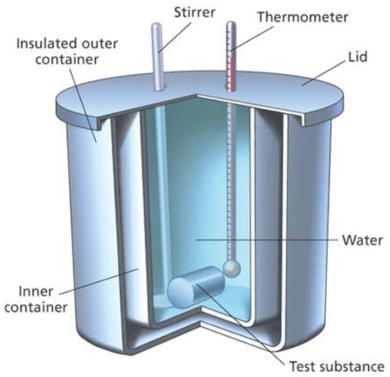
$$Q_A\ -\ Q_B\ = 0 \quad \rightarrow \quad Q_A\ =\ -\ Q_B$$

What this means:

$$m_A C_A\ \Delta T_A\ =\ -\ m_B C_B\ \Delta T_B$$

$$\Delta T_= T_f - T_i$$

Calorimeter



Thermal Equilibrium Problems

- Sketch a before-after picture to help see the problem
- Label all known variables

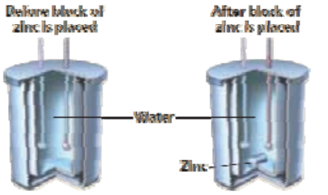
  Remember T_f will be the same for all materials
- Set up your equation

  Heat lost = Heat gained

  $Q_A = - Q_B$
- Solve for your unknown variable
- Plug and chug

Thermal Equilibrium Example

A calorimeter contains 0.50 kg of water at 15°C. A 0.040 kg block of zinc at 115°C is placed in the water. What is the final temperature of the water?



$m_Z = 0.040$ kg
$C_Z = 388$ J/kg·°C
$T_Z = 115$°C

$m_W = 0.50$ kg
$C_W = 4180$ J/kg·°C
$T_W = 15$°C

$T_f = ?$

Thermal Equilibrium

Solve for T_f – This will be the same for both objects

Heat lost $Q_Z = -Q_W$ Heat gained

Set up equation $m_Z C_Z (T_Z - T_f) = -m_W C_W (T_W - T_f)$

Distribute $m_Z C_Z T_Z - m_Z C_Z T_f = -m_W C_W T_W + m_W C_W T_f$

Combine like terms $m_Z C_Z T_Z + m_W C_W T_W = m_Z C_Z T_f + m_W C_W T_f$

Separate T_f $m_Z C_Z T_Z + m_W C_W T_W = (m_Z C_Z + m_W C_W) T_f$

Thermal Equilibrium

Solve for T_f – This will be the same for both objects

$$T_f = \frac{m_Z C_Z T_Z + m_W C_W T_W}{m_Z C_Z + m_W C_W}$$

$$T_f = \frac{(0.040)(388)(115) + (0.50)(4180)(15)}{(0.040)(388) + (0.50)(4180)}$$

$$T_f = 16°\text{C}$$

This means the final temperature of both the water and zinc should be about 16°C

Phase Changes

Phase changes occur at constant temperature

Heat of Fusion (H_f) – energy required to melt a solid

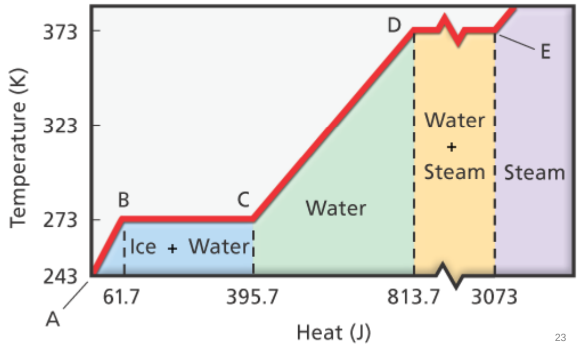
$Q = m H_f$

Heat of Vaporization (H_v) – energy required to vaporize a liquid

$Q = m H_v$

Units are [J/kg]

Change of State Graph



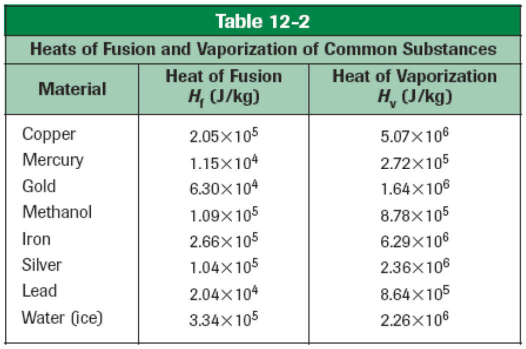


Table 12-2

Heats of Fusion and Vaporization of Common Substances

Material	Heat of Fusion H_f (J/kg)	Heat of Vaporization H_v (J/kg)
Copper	2.05×10^5	5.07×10^6
Mercury	1.15×10^4	2.72×10^5
Gold	6.30×10^4	1.64×10^6
Methanol	1.09×10^5	8.78×10^5
Iron	2.66×10^5	6.29×10^6
Silver	1.04×10^5	2.36×10^6
Lead	2.04×10^4	8.64×10^5
Water (ice)	3.34×10^5	2.26×10^6

Thermodynamics

0.05kg Ice is dropped in 50ΔU = Q - W

U is the internal energy of a substance

Q = Heat added to the system

W = Work done by the system

Example: Hitting a nail with a hammer – work done to the hammer gives a negative W value.

ΔU increases and temperature may go up.

Thermodynamics

0th Law of Thermodynamics: A system left alone will move towards thermal equilibrium.

“Everything wants to go to bed and lie down”

Ex: Mixing hot water and cold water will eventually have a uniform temperature.

Thermodynamics

1st Law of Thermodynamics: ΔU = Q - W

U is the internal energy of a substance

Q = Heat added to the system

W = Work done by the system

Example: Hitting a nail with a hammer – work done to the hammer gives a negative W value.

ΔU increases and temperature may go up.

Work Put Out

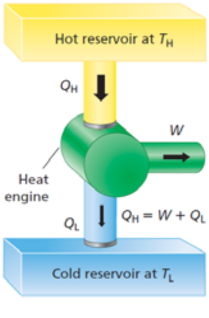


Figure 12-11 A heat engine transforms heat at high temperature into mechanical energy and low-temperature waste heat.

Work Put In

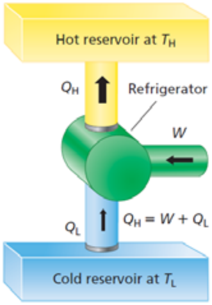


Figure 12-13 A refrigerator absorbs heat, Q_L, from the cold reservoir and gives off heat, Q_H, to the hot reservoir. Work, W, is done on the refrigerator.

Thermodynamics

2nd Law of Thermodynamics: $\Delta S = \frac{Q}{T}$

S is the entropy of a substance. This is a measure of disorder in an object. The universe favors an increase in entropy.

Q = Heat added to the object

T = Temperature of object

Adding heat increases entropy, more disordered.

Ex. gases will move more, etc.

Taking away heat makes things more ordered.

Ex. Heat taken from a liquid can turn it to a solid.

2nd Law of Thermodynamics: Significance

A hot body losing heat to a cold body

$$\Delta S = \frac{Q(\text{negative value})}{T_{High}} = \text{small negative } \Delta S$$

A cold body losing heat to a hot body

$$\Delta S = \frac{Q(\text{positive value})}{T_{Low}} = \text{large positive } \Delta S$$

Put together, entropy favors hot to cold:

Absolute 0 is impossible

Thermodynamics

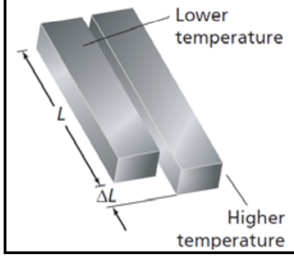
3^{rd} Law of Thermodynamics: As a system approaches absolute zero, all processes cease and the system entropy approaches a minimum value.

Some say if we could reach absolute 0, a perfect crystal could have 0 entropy.

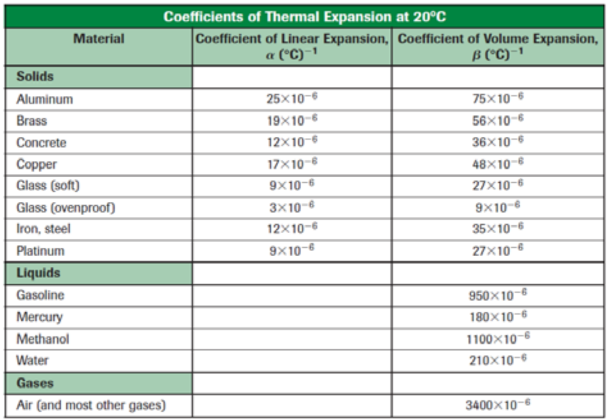
Thermal Expansion

The change in length of a material is proportional to the original length and the change in temperature

$$\Delta L = \alpha L_i \Delta T \qquad \Delta V = \beta V_i \Delta T$$



α = coeff of linear expansion
β = coeff of volume expansion
ΔT = change in temperature
ΔL = change in length
L_i = original length
ΔV = change in volume
V_i = original volume



Coefficients of Thermal Expansion at 20°C		
Material	**Coefficient of Linear Expansion, α (°C)$^{-1}$**	**Coefficient of Volume Expansion, β (°C)$^{-1}$**
Solids		
Aluminum	25×10^{-6}	75×10^{-6}
Brass	19×10^{-6}	56×10^{-6}
Concrete	12×10^{-6}	36×10^{-6}
Copper	17×10^{-6}	48×10^{-6}
Glass (soft)	9×10^{-6}	27×10^{-6}
Glass (ovenproof)	3×10^{-6}	9×10^{-6}
Iron, steel	12×10^{-6}	35×10^{-6}
Platinum	9×10^{-6}	27×10^{-6}
Liquids		
Gasoline		950×10^{-6}
Mercury		180×10^{-6}
Methanol		1100×10^{-6}
Water		210×10^{-6}
Gases		
Air (and most other gases)		3400×10^{-6}