

Thermodynamics

Auburn Mountainview: Physics

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Temperature

- There are three major systems of measuring temperature.
 - Celsius (Water Freezes/Boils: 0°/100°)
 - Fahrenheit (Water Freezes/Boils: 32°/212°)
 - Kelvin (Water Freezes/Boils: 273.15/373.15)
- F→C: $T_F = (9/5)T_C + 32$
- C→K: $T_K = T_C + 273.15$

Linear Expansion

- When heated up a solid will expand.
 - The expansion in any one dimension is called Linear Thermal Expansion.

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

- The expansion in all dimensions is called Volume Thermal Expansion.

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

Selected Substances 1

Substance	Coef. of Thermal Expansion (α) ($^{\circ}\text{C}^{-1}$)	Coef. of Thermal Expansion (β) ($^{\circ}\text{C}^{-1}$)	Specific Heat Capacity ($\text{J}/\text{Kg}\cdot^{\circ}\text{C}$)
Aluminum	23.00×10^{-6}	69.00×10^{-6}	900.00
Brass	19.00×10^{-6}	57.00×10^{-6}	380.00
Concrete	12.00×10^{-6}	36.00×10^{-6}	960.00
Copper	17.00×10^{-6}	51.00×10^{-6}	387.00
Glass (B-Si)	8.50×10^{-6}	26.00×10^{-6}	840.00
Glass (Pyrex)	3.30×10^{-6}	9.90×10^{-6}	750.00
Gold	14.00×10^{-6}	42.00×10^{-6}	129.00
Iron/Steel	12.00×10^{-6}	36.00×10^{-6}	452.00
Lead	29.00×10^{-6}	87.00×10^{-6}	128.00
Nickel	13.00×10^{-6}	39.00×10^{-6}	444.00
Quartz	0.50×10^{-6}	1.50×10^{-6}	800.00
Silver	19.00×10^{-6}	57.00×10^{-6}	235.00

Selected Substances 1

Substance	Coef. of Thermal Expansion (β) ($^{\circ}\text{C}^{-1}$)	Specific Heat Capacity ($\text{J}/\text{Kg}\cdot^{\circ}\text{C}$)
Benzene	1240.00×10^{-6}	1740.00
CCl_4	1240.00×10^{-6}	866.00
Ethyl Alcohol	1120.00×10^{-6}	2450.00
Gasoline	950.00×10^{-6}	2220.00
Mercury	182.00×10^{-6}	139.00
Methyl Alcohol	1200.00×10^{-6}	2510.00
Ice	51.00×10^{-6}	2000.00
Water	207.00×10^{-6}	4186.00
Human Body		3500.00

Example 1

- Two 3.00-m concrete sidewalk slabs ($\alpha=12 \times 10^{-6}\text{-}^{\circ}\text{C}^{-1}$) at $25.00\text{-}^{\circ}\text{C}$ is between two buildings. When the temperature raises to $38.00\text{-}^{\circ}\text{C}$ calculate how high the slabs buckle.

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

$$\Delta L = 12 \times 10^{-6} \cdot 3.00\text{-m} \cdot 13.00$$

$$\Delta L = 4.68 \times 10^{-4}\text{-m}$$

$$\Delta L =$$

$$\alpha = 12 \times 10^{-6}\text{-}^{\circ}\text{C}^{-1}$$

$$L_0 = 3.00\text{-m}$$

$$\Delta T = 38\text{-}25\text{-}^{\circ}\text{C}$$

Example 1 Cont.

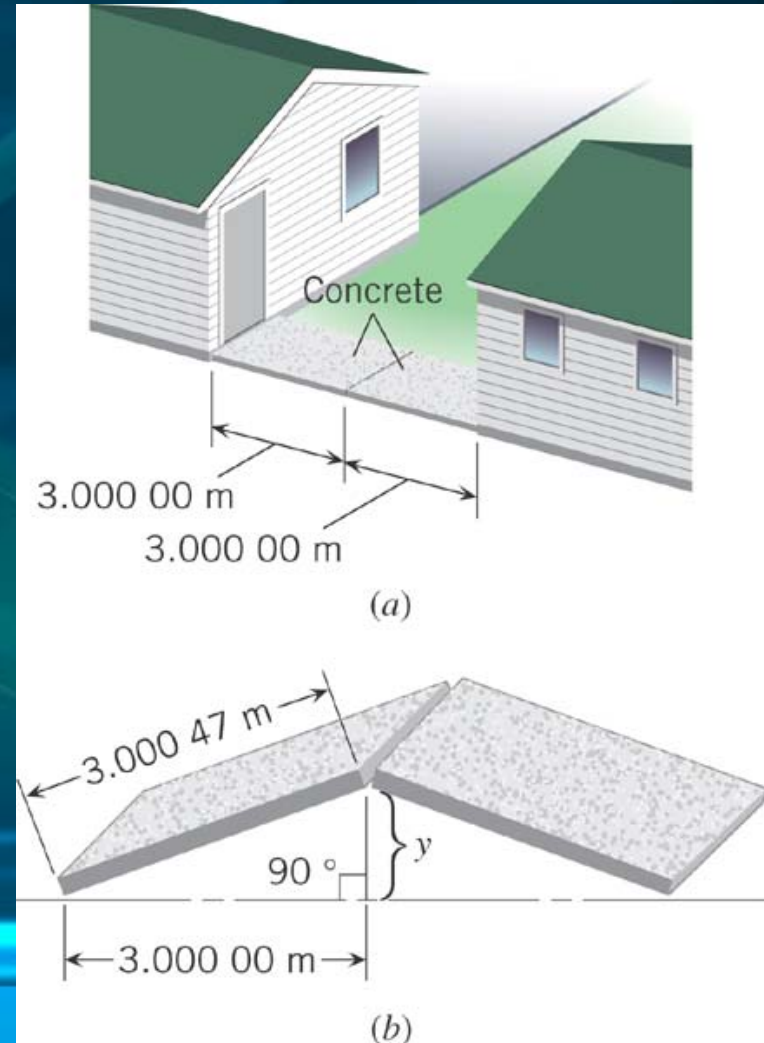
- Using the original length as the base and new length as a hypotenuse, solve for the height.

$$(3.00047\text{-m})^2 = (3.00\text{-m})^2 + h^2$$

$$h^2 = .002820\text{-m}^2$$

$$h = .0531\text{-m}$$

$$h = 5.31 \times 10^{-2}\text{-m or } 5.31\text{-cm}$$



Heat

- Heat is the amount of energy (J) that flows from a high temp source to a low one.
- Solids and Liquids hold heat differently so they have specific heats; c .
- The heat (Q) needed to increase an objects temperature is defined by;

$$Q = cm\Delta T$$

Example 2

- To take a shower water (15.00-°C) enters a heater. A person uses 120-kg of hot water (61.00-°C). How much heat is needed for this? If the utility company charges 10-¢/kW·hr, how much does this cost?

$$Q = cm\Delta T$$

$$Q = 4186\text{-J/Kg}\cdot^{\circ}\text{C}\cdot 120\text{-kg}\cdot 46\text{-}^{\circ}\text{C}$$

$$Q = 23106720\text{-J}$$

$$Q = 2.31 \times 10^7\text{-J}$$

$$Q =$$

$$c = 4186\text{-J/Kg}\cdot^{\circ}\text{C}$$

$$m = 120\text{-kg}$$

$$\Delta T = 61\text{-}15\text{-}^{\circ}\text{C}$$

Example 2 Cont.

- How much does this cost?
 - Remember $1\text{-W} = 1\text{-J/s}$
 - Using dimensional analysis:

$$Q = 2.31 \times 10^7\text{-J} \cdot 1\text{-W}/1\text{-J/s}$$

$$C = 10\text{-}\phi/\text{kW}\cdot\text{hr}$$

$$Q = 2.31 \times 10^7\text{-Ws} \cdot 1\text{-hr}/3600\text{-s}$$

$$Q = 6418.5\text{-Whr} \cdot 1\text{-kW}/1000\text{-W}$$

$$Q = 6.4185\text{-kW}\cdot\text{hr}$$

$$\text{Cost} = Q \cdot C$$

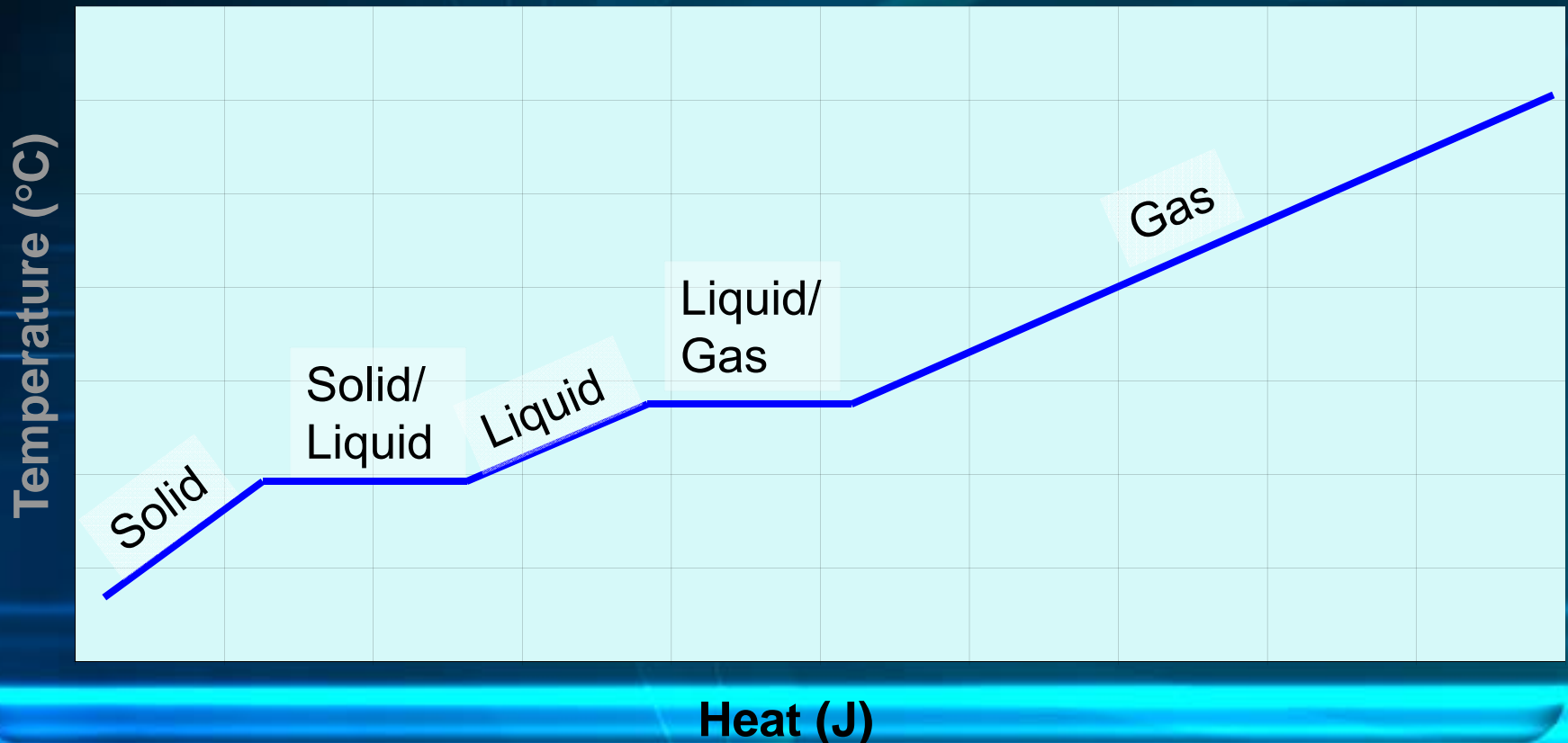
$$\text{Cost} = 6.4185\text{-kW}\cdot\text{hr} \cdot 10\text{-}\phi/\text{kW}\cdot\text{hr}$$

$$\text{Cost} = 64.19\text{-}\phi$$

Phase Changes

- Look at the below graph of a typical material.

Phase Change Diagram



Key Parts

- The temperature does not change while changing from solid to liquid and liquid to gas.
 - Solid \leftrightarrow Liquid: Freezing or Melting
 - Liquid \leftrightarrow Gas: Condensing or Evaporating
- For changing a phase state, every substance has its own amount of Heat (J) needed to convert all of it to the new phase.

Latent Heat

- This amount of heat needed to be added or removed for each substance is called Latent Heat; L (J/kg).

$$Q = mL$$

- For Solid \leftrightarrow Liquid: Latent Heat of Fusion L_F
- For Liquid \leftrightarrow Gas: Latent Heat of Vaporization L_V
- Remember while either solid, liquid, or gas the heat needed is: $Q = cm\Delta T$.

Selected Substances 3

Substance	Melting Point (°C)	Latent Heat of Fusion (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization (J/kg)
Ammonia	-77.80	33.20×10^4	-33.40	13.70×10^5
Benzene	5.50	12.60×10^4	80.10	3.94×10^5
Copper	1083.00	20.70×10^4	2566.00	47.30×10^5
Ethyl Alcohol	-114.40	10.80×10^4	78.30	8.55×10^5
Gold	1063.00	6.28×10^4	2808.00	17.20×10^5
Lead	327.30	2.32×10^4	1750.00	8.59×10^5
Mercury	-38.90	1.14×10^4	356.60	2.96×10^5
Nitrogen	-210.00	2.57×10^4	-195.80	2.00×10^5
Oxygen	-218.00	1.39×10^4	-183.00	2.13×10^5
Silver	961.78	10.46×10^4	2162.00	53.96×10^5
Water	0.00	33.50×10^4	100.00	22.6×10^5

Example 3

- To make a ring 20.00-g of silver need heated to 1200.00-°C. Assuming the silver starts at room temperature (20.00-°C), how much heat is needed?

Substance	Melting Point (°C)	Latent Heat of Fusion (J/kg)	Boiling Point (°C)	Specific Heat Capacity (J/Kg•°C)
Silver	961.78	10.46×10^4	2162.00	235.00



Example 3 Cont.

- This problem has three parts:
 1. Heating the Solid Silver (20.00-°C→961.78-°C)
 2. Melting the Silver (Heat Latent Fusion)
 3. Heating the Liquid Silver (961.78-°C→1200.00-°C)
 - As 1. + 3. use the same 'c' they may be combined.

$$\Sigma Q = Q_1 + Q_2 = cm\Delta T + mL$$

$$Q_1 = 20 \times 10^{-3} \cdot 235 \cdot 1180\text{-J}$$

$$Q_2 = 20 \times 10^{-3} \cdot 10.46 \times 10^4\text{-J}$$

$$\Sigma Q = 14454\text{-J} + 2092\text{-J}$$

$$\Sigma Q = 1.65 \times 10^4 \text{-J}$$

$$Q =$$

$$c = 235\text{-J/Kg}\cdot^\circ\text{C}$$

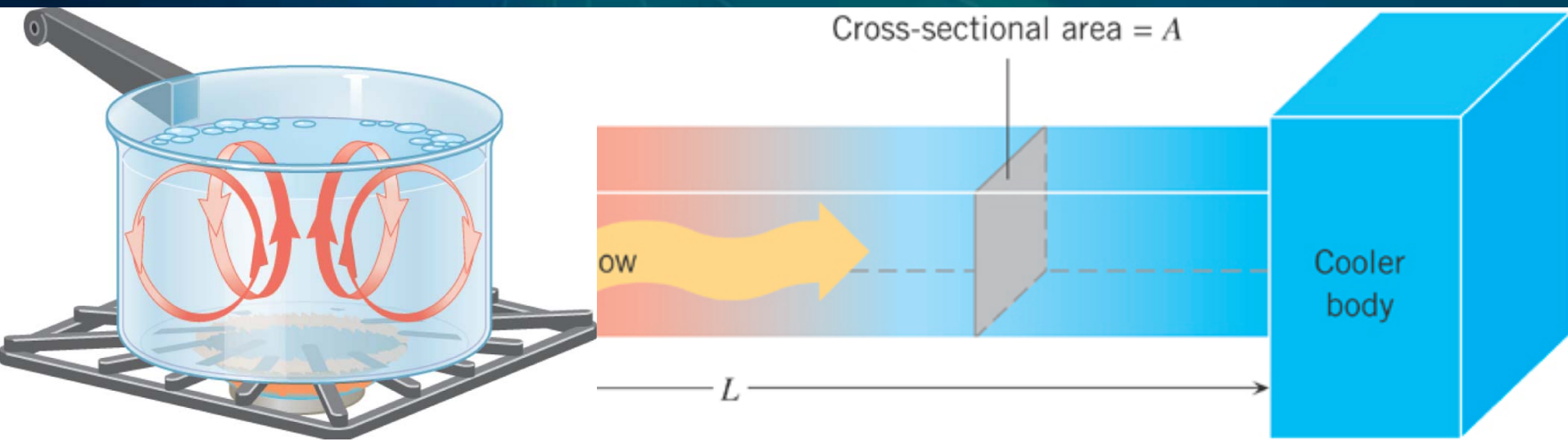
$$m = 20\text{-g}$$

$$\Delta T = 1200\text{-}20\text{-}^\circ\text{C}$$

$$L = 10.46 \times 10^4\text{-J/kg}$$

Transferring Heat

- There are three ways to transfer heat.
 - Convection: Transfer due to the bulk movement of a fluid.
 - Conduction: Transfer directly through a material.
 - Radiation: Transfer by electromagnetic radiation.



Conduction

- Heat can be considered a fluid.
 - Due to gravity, a liquid will flow from high to low.
 - Heat flows from a higher to lower source.
- Conduction occurs when a material is touching a source with more heat.
- The material will increase by:

$$Q = (kA\Delta T)tL^{-1}$$

Q = Heat (J)

k= Thermal Conductivity (J/s•m• °C)

A= Cross Area (m²)

ΔT = Temp (°C)

t = time (s)

L= Length (m)

Selected Substances 4

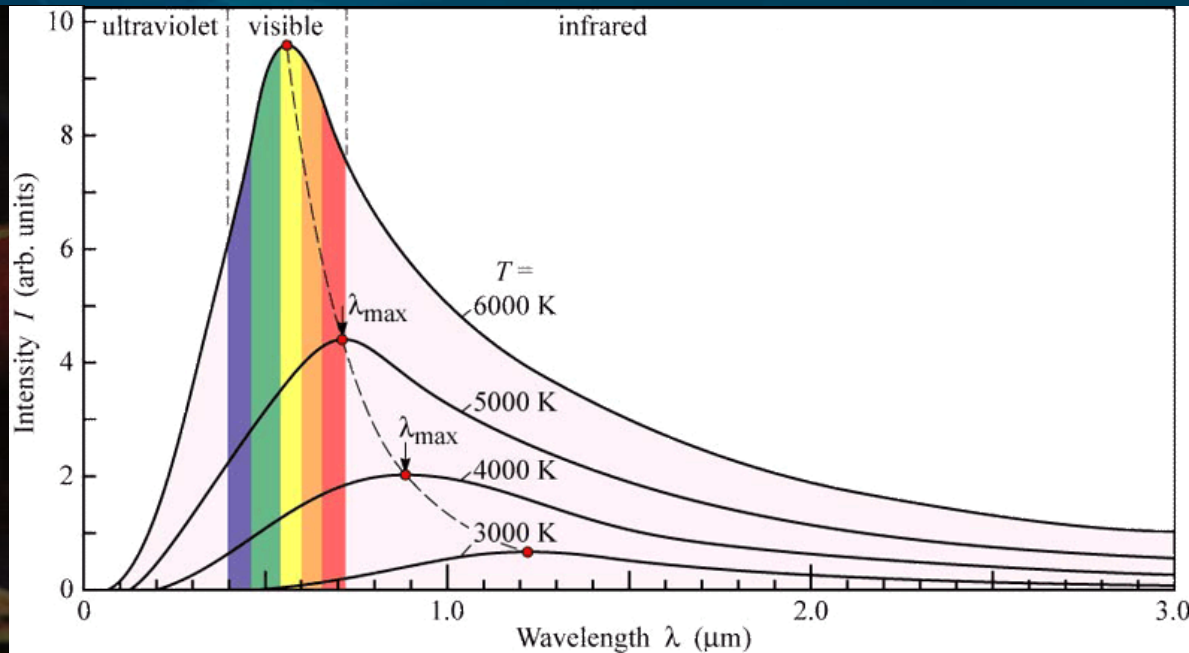
Substance	Thermal Conductivity (J/s•m• °C)	Substance	Thermal Conductivity (J/s•m• °C)
Aluminum	240.00	Asbestos	9.00 x 10⁻²
Brass	110.00	Body Fat	2.00 x 10⁻¹
Copper	390.00	Concrete	1.10
Iron	79.00	Diamond	2450
Lead	35.00	Glass	8.00 x 10⁻¹
Silver	420.00	Goose Down	2.50 x 10⁻²
Steel	14.00	Ice	2.20
Air	2.56 x 10⁻²	Styrofoam	1.10 x 10⁻²
Hydrogen Gas	1.80 x 10⁻¹	Water	6.00 x 10⁻¹
Nitrogen Gas	2.58 x 10⁻²	Wood	1.50 x 10⁻¹
Oxygen Gas	2.65 x 10⁻²	Wool	4.00 x 10⁻²

Radiation

- The sun gives off a full spectrum of visible electromagnetic radiation.
 - Black objects absorb radiation, White objects reflect it.
 - Any object that absorbs all of this is called a perfect blackbody.
 - In reality all objects do radiate electromagnetic radiation.
- Any object that absorbs radiation is also a good emitter, and vice versa.

Blackbody Radiation Curves

- All object no matter what temperature, gives off electromagnetic radiation.
- At a given temperature, different frequencies will be emitted at different intensities.



Planck's Constant

- Max Planck calculated that the energy given off by the black bodies had discrete values (n) based off the frequency.

$$E = nhf$$

$$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s}$$

- Atomically radiation is released at set levels.
- This was against the norm as previous physics thought that any energy amount should be allowed to radiate.

Stefan-Boltzmann's Law

- The ratio of how much an object radiates is called the emissivity (1-0 or 100%-0%).
- The radiant energy Q , emitted in time t by an object that has a temperature (in K) T , surface area A and emissivity e is given by:

$$Q = e\sigma T^4 A t$$

- $\sigma = 5.67 \times 10^{-8} \text{ J/s} \cdot \text{m}^2 \cdot \text{K}^4$
 - This is the Stefan-Boltzman Constant

Example 4

- Betelgeuse, a supergiant star, has a surface temperature of about 2900.00-K (1/2 the sun) and emits a radiant power of 4.00×10^{30} -W (10,000 sun's). Assuming it is a perfect emitter, and spherical, find the radius.

– Hint stating the power gives us both Q and t!

$$4 \times 10^{30}\text{-J} = 1 \cdot 5.67 \times 10^{-8}\text{-J}\cdot\text{m}^{-2}\cdot 2900^4 \cdot A \cdot 1$$

$$A = 9.97 \times 10^{23}\text{-m}^2$$

$$\text{For a sphere } A = 4\pi r^2$$

$$9.97 \times 10^{23}\text{-m}^2 = 4\pi r^2$$

$$r = 2.82 \times 10^{11}\text{-m}$$

$$Q = 4 \times 10^{30}\text{-J}$$

$$e = 1$$

$$\sigma = 5.67 \times 10^{-8}\text{-J/s}\cdot\text{m}^2\cdot\text{K}^4$$

$$T = 2900\text{-K}$$

$$A =$$

$$t = 1\text{-s}$$

Distance Sun \rightarrow Jupiter = $7.79 \times 10^{11}\text{-m}$

Basic Properties of Gas

- 1 mole of gasses at 1-atm, 0-°C occupy the same space (22.4-L)
- Gasses can be compressed.
- Gasses expand to fill their container.
- Gasses can move through each other.
- Gasses do not exert a significant force on each other (Gravity v. mass)

Basic Properties Continued

- Gasses constantly travel in random directions.
- Gasses have a high amount of Kinetic Energy.
- The amount of energy is proportional to the temperature of the gas.

Kinetic Theory

- Gas molecules constantly hit the side of its container and other molecules.
 - The more they hit the side of the wall the more the pressure on the wall.
 - These impacts do not reduce the energy of the molecule (elastic collision).
- The Kinetic Energy is defined by the average value of the speed (root mean squared)

$$KE = \frac{3}{2} kT$$

k = Boltzman's constant = 1.38×10^{-23} -J/K

Kinetic Theory

- The last formula was dependant only on the temperature.
- The speed the gas travels by is defined as:

$$v_{\text{rms}} = \sqrt{(3RT/M)} \quad \text{or} \quad v_{\text{rms}} = \sqrt{(3kT/\mu)}$$

R= Univ. Gas Cons.

k= Boltzman's c

R= 8.31-J/mol•K

k= 1.38×10^{-23} -J/K

T= Temperature (K)

T=Temperature (K)

M= Molar Mass (kg/mol)

μ = Mass of Mol (kg)