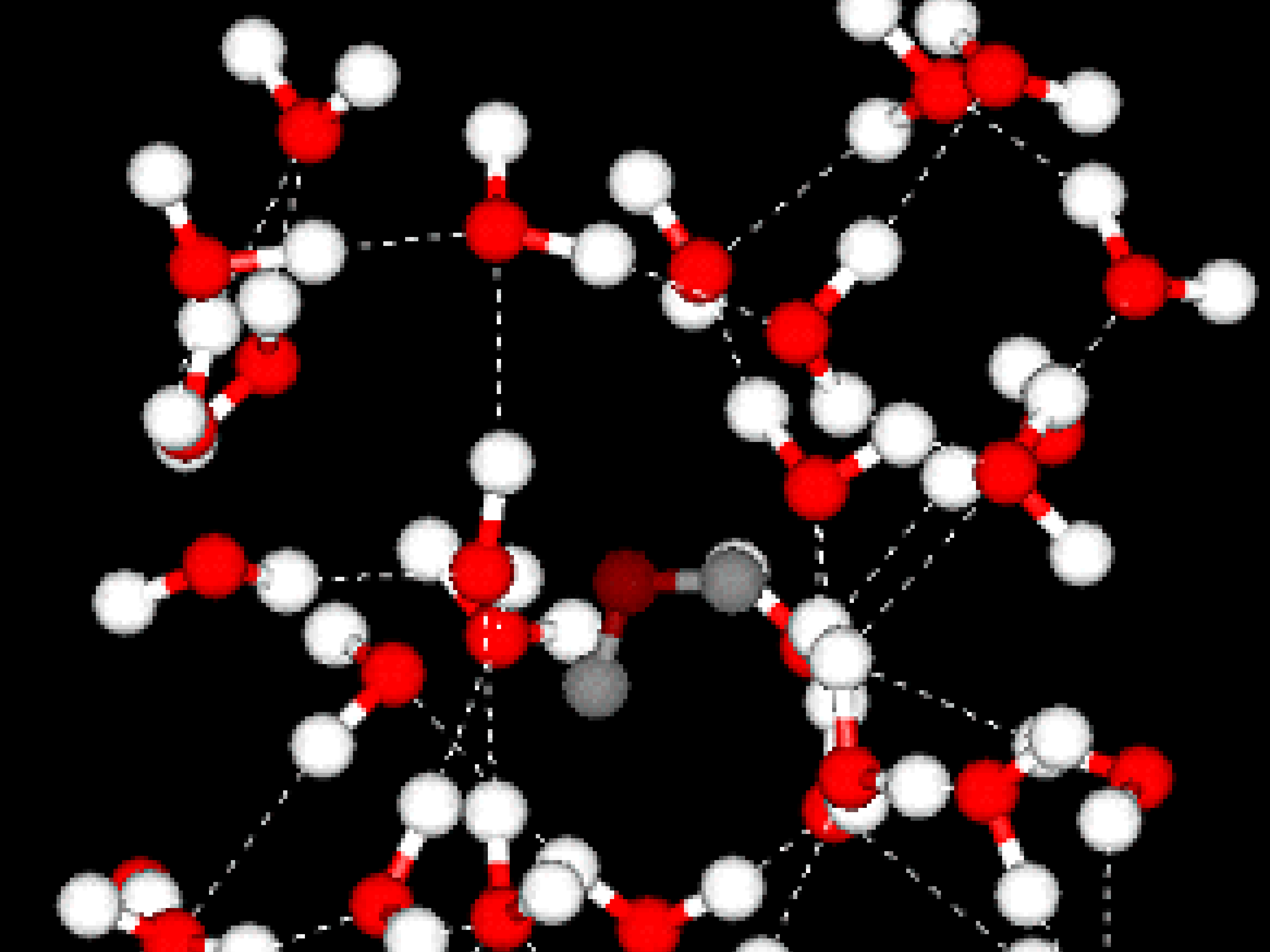
Thermal Energy

What is Internal Energy?

- Individual molecules making up a body have energy
- Even in a solid, the vibration of the molecules give them kinetic energy
- The electromagnetic force between the molecules give them potential energy
- Internal energy is a combination of this kinetic and potential energy



Temperature

- Temperature is based on the average kinetic energy of the molecules
- T is therefore independent of mass
- We define $0^{o}C$ as the freezing point of water, $100^{o}C$ as its boiling point
- The Kelvin scale defines 0K as absolute zero: no molecular motion!
- To convert: $0\ K = -273\ ^{o}C$ so $K = {}^{o}C + 273$

Thermal Energy

- Thermal energy (Heat) is defined as the transfer of internal energy by:
  - conduction
  - convection, or
  - radiation


- Heat Q can be found by

$$Q=mc\Delta T$$

where c is a substance's specific heat capacity

Ex 1: How much heat is necessary to bring 0.100L of water from 40ºC to 100ºC ?

$Q=mc\Delta T$

$=0.100\text{kg}(4200\text{J/kg}^{\circ}\text{C})60^{\circ}\text{C}$

$=25\text{ kJ}$

- What is the power of a hot plate that heats 0.100L of water in 2.5 minutes?

Q=mcΔT

$$P = \frac{mc\Delta T}{t}$$

$$P = \frac{0.10kg(4200)80}{150}$$

$$P = 224W$$

- What is the latent heat of vaporization if 25 mL of water are “missing” after 4 minutes of boiling?

Q=mL

$$P = \frac{mL}{t} \qquad L = \frac{Pt}{m}$$

$$L = \frac{224(240)}{0.025}$$

$$L = 2.2 \times 10^{6} J \cdot kg^{-1}$$

- Heating up lab p. 143 (Gore)
- Choice of heating devices:
    - Bunsen burner
    - Hot plate
    - Heat lamp?
  - Power calculations
  - Add: measure mass before and after, find heat of vaporization
- Evaluation: state results, sources of error, possible improvements

The mole

Avogadro's number tells us how many particles in 12 grams of carbon 12

$$6.022 \times 10^{23}$$

Ex: how many molecules are in one drop of water?

a) 10^{19}

b) 10^{21}

c) 10^{23}

d) 10^{25}

Avogadro's number

$$6.023 \cdot 10^{23}$$

- Ex: what is the mass of one mole of water?
- 16+1+1=18g
- What is the mass of water that has the double the number of molecules as 11g of quicksilver?
- Hydrargyrum?
- Hg?

Ex: how many water molecules are in one drop of water (0.1mL) if the density of the water is 1.01g/mL (kg/L)?

$$0.1mL \times \frac{1.01g}{mL} \times \frac{1mol}{18g} \times \frac{6.022 \times 10^{23} molecules}{1mol}$$

$$3.4 \times 10^{21} molecules$$

Choose 6 questions 1-12 p. 125

We can use E conservation to solve problems involving heat

Ex 2: How much heat is generated when we strike an anvil with a 25 kg hammer at 13m s^{-1} ?

$E_k = 1/2mv^2$

$= 0.5(25)13^2$

$= 2100J$

Try 3-4 p. 69

We can use E conservation to solve problems involving heat

Ex 2: How much 75 ^oC aluminum will it take to heat 100 mL room temperature water to 65 ^oC ?

$\Delta E=0$

$$m_a c_a \Delta T_a = -m_w c_w \Delta T_w$$

$m_{a=}$?

$c_{a=}$903J/kg ºC

$\Delta T_{a=}$-10 ºC

$m_{w=}$0.100kg

$c_{w=}$4180J/kgºC

ΔT_w =45 ºC

$$m_a c_a \Delta T_a = -m_w c_w \Delta T_w$$

$$m_a = \frac{-m_w c_w \Delta T_w}{c_a \Delta T_a}$$

$$m_a = \frac{-0.10kg \cdot 4180 \, {}^{J}\!/\!_{kg^\circ C} \cdot 45^\circ C}{903 \, {}^{J}\!/\!_{kg^\circ C} (-10^\circ C)}$$

$$m_a = 2.1kg$$

Ex 3: "Mystery" object

- what is the specific heat of a substance that decreases the temperature of 200mL 85 ºC water by 5ºC when you drop in a 0.045kg block at 20ºC? What is it?

$m_{x=}$0.045kg

$c_{x=}$?

ΔT_x=60 ºC

$m_{w=}$0.2kg

$c_{w=}$4200J/kgºC

ΔT_w =-5ºC

$$Q_x = -Q_w$$

$$m_x c_x \Delta T_x = -m_w c_w \Delta T_w$$

$$c_x = \frac{-m_w c_w \Delta T_w}{m_x \Delta T_x}$$

$$c_x = \frac{-0.2kg \cdot 4200\, J/kg°C \cdot (-5°C)}{0.045kg \cdot 60°C}$$

$$c_x = 1600\, J/kg°C$$

Ex 3: "Mystery" object

- what is the specific heat of a substance that decreases the temperature of 200mL 77.6 ºC water to 71.4ºC when you drop in a 0.045kg block at 21.5ºC? What is it?

$m_{x=}0.0621\text{kg}$

$c_{x=}?$

$\Delta T_x = 49.9\,^{o}\text{C}$

$m_{w=}0.2\text{kg}$

$c_{w=}4200\text{J/kg}^{o}\text{C}$

$\Delta T_w = -6.4^{o}\text{C}$

$$Q_x = -Q_w$$

$$m_x c_x \Delta T_x = -m_w c_w \Delta T_w$$

	kJ						
Aluminum	0.91	Gold	0.13	Osmium	0.13	Tantalum	0.14
Antimony	0.21	Hafnium	0.14	Palladium	0.24	Thallium	0.13
Barium	0.2	Indium	0.24	Platinum	0.13	Thorium	0.13
Beryllium	1.83	Iridium	0.13	Plutonium	0.13	Tin	0.21
Bismuth	0.13	Iron	0.45	Potassium	0.75	Titanium	0.54
Cadmium	0.23	Lanthanum	0.195	Rhenium	0.14	Tungsten	0.13
Calcium	0.63	Lead	0.13	Rhodium	0.24	Uranium	0.12
Carbon Steel	0.49	Lithium	3.57	Rubidium	0.36	Vanadium	0.39
Cast Iron	0.46	Lutetium	0.15	Ruthenium	0.24	Yttrium	0.3
Cesium	0.24	Magnesium	1.05	Scandium	0.57	Zinc	0.39
Chromium	0.46	Manganese	0.48	Selenium	0.32	Zirconium	0.27
Cobalt	0.42	Mercury	0.14	Silicon	0.71	Wrought Iron	0.5
Copper	0.39	Molybdenum	0.25	Silver	0.23		
Gallium	0.37	Nickel	0.44	Sodium	1.21		
Germanium	0.32	Niobium	0.27	Strontium	0.3		

$$c_x = \frac{-m_w c_w \Delta T_w}{m_x \Delta T_x}$$

$$c_x = \frac{-0.2kg \cdot 4200 \,{}^{J}\!/_{kg^\circ C} \cdot (-6.4^\circ C)}{0.0621kg \cdot 49.9^\circ C}$$

$$c_x = 1600 \,{}^{J}\!/_{kg^\circ C}$$

- Mystery metal activity: 1 write-up for each group of 2-3 people
  - Measure 200 mL of cold water into your styrofoam calorimeter
  - Measure the initial temperature of the water and metal
  - Drop the hot metal into the water and seal the container
  - After 2 minutes, measure final temperature, then calculate “c”

Ex 4: unknown T!

- what will the final temperature be if you drop a 0.45kg block of copper at 340ºC into 0.750 L room temperature water?

$m_{c=}0.45kg$

$c_{c=}385J/kg\,^{o}C$

$\Delta T_{c=}?$

$m_{w=}0.75kg$

$c_{w=}4180J/kg^{o}C$

$\Delta T_{w} =?$

$$Q_c = -Q_w$$

$$m_c c_c \Delta T_c = -m_w c_w \Delta T_w$$

$$m_c c_c \left(T_f - T_{ci}\right) = -m_w c_w \left(T_f - T_{wi}\right)$$

$$m_c c_c T_f - m_c c_c T_{ci} = -m_w c_w T_f + m_w c_w T_{wi}$$

$$m_c c_c T_f + m_w c_w T_f = m_c c_c T_{ci} + m_w c_w T_{wi}$$

$$\left(m_c c_c + m_w c_w\right) T_f = m_c c_c T_{ci} + m_w c_w T_{wi}$$

$$T_f = \frac{m_c c_c T_{ci} + m_w c_w T_{wi}}{m_c c_c + m_w c_w}$$

$m_{c=}0.45kg$

$c_{c=}385J/kg\ ^oC$

$\Delta T_{c=}?$

$m_{w=}0.75kg$

$c_{w=}4180J/kg^oC$

$\Delta T_w =?$

$$T_f = \frac{m_c c_c T_{ci} + m_w c_w T_{wi}}{m_c c_c + m_w c_w}$$

$$T_f = \frac{0.45kg \cdot 385J/kg°C \cdot 340°C + 0.75kg \cdot 4180J/kg°C \cdot 20°C}{0.45kg \cdot 385J/kg°C + 0.75kg \cdot 4180J/kg°C}$$

$$T_f = 37°C$$

Do questions 7-11 p. 73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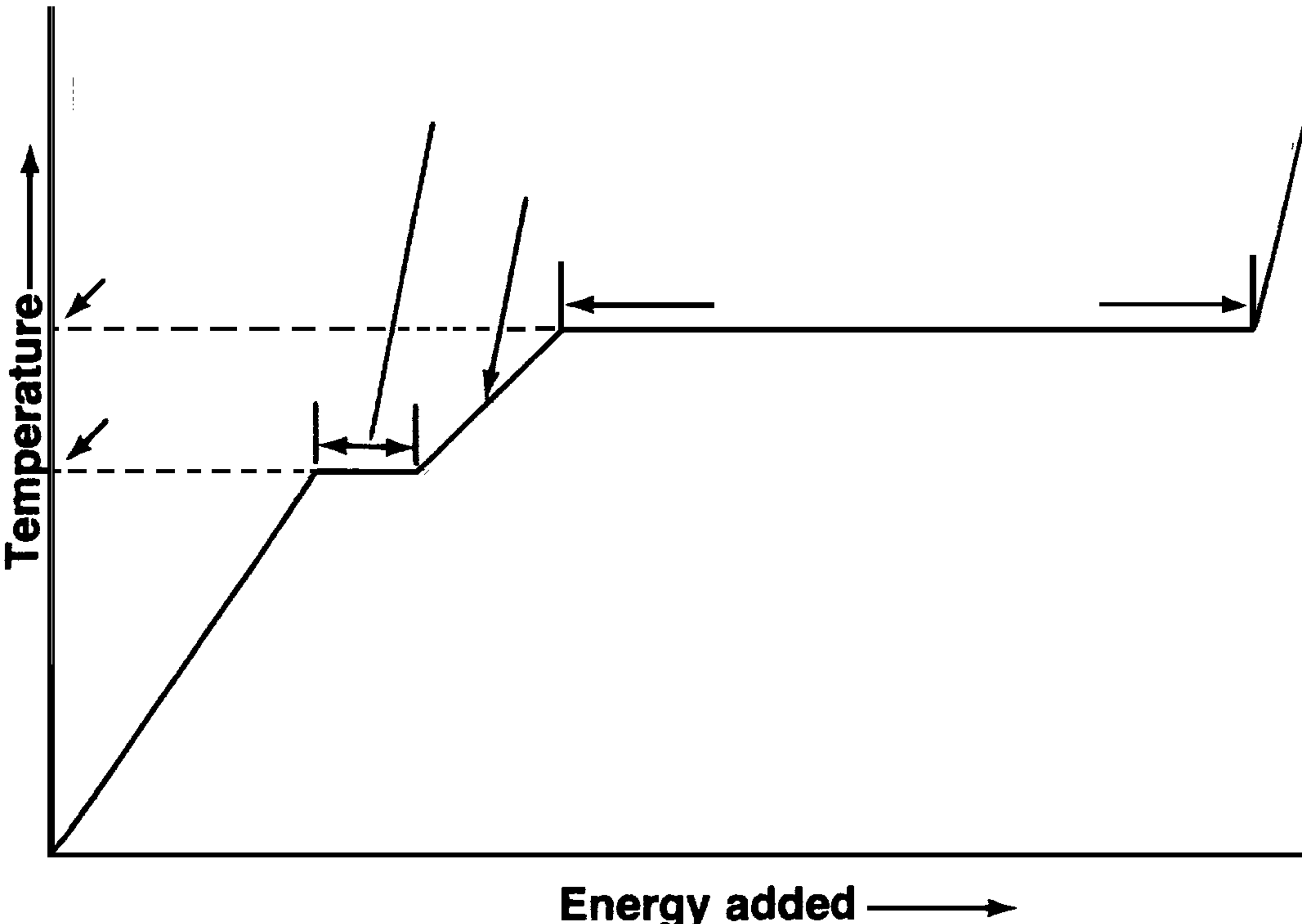
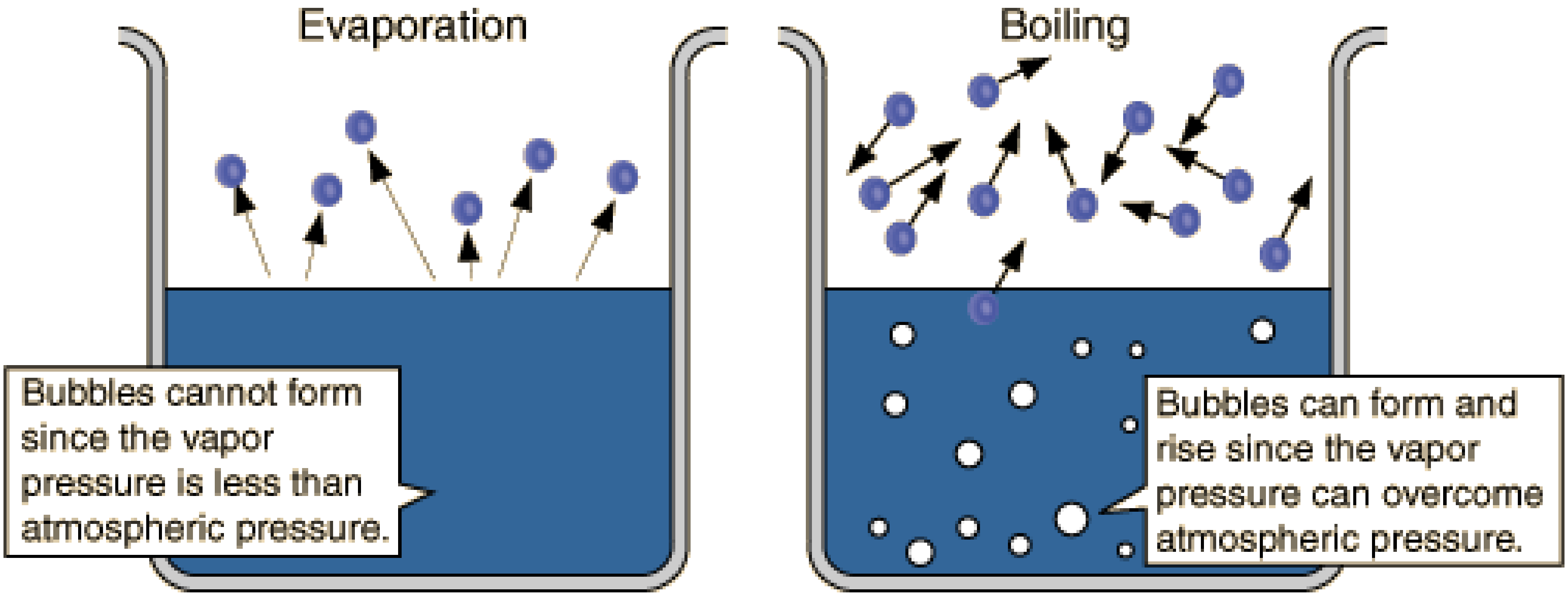


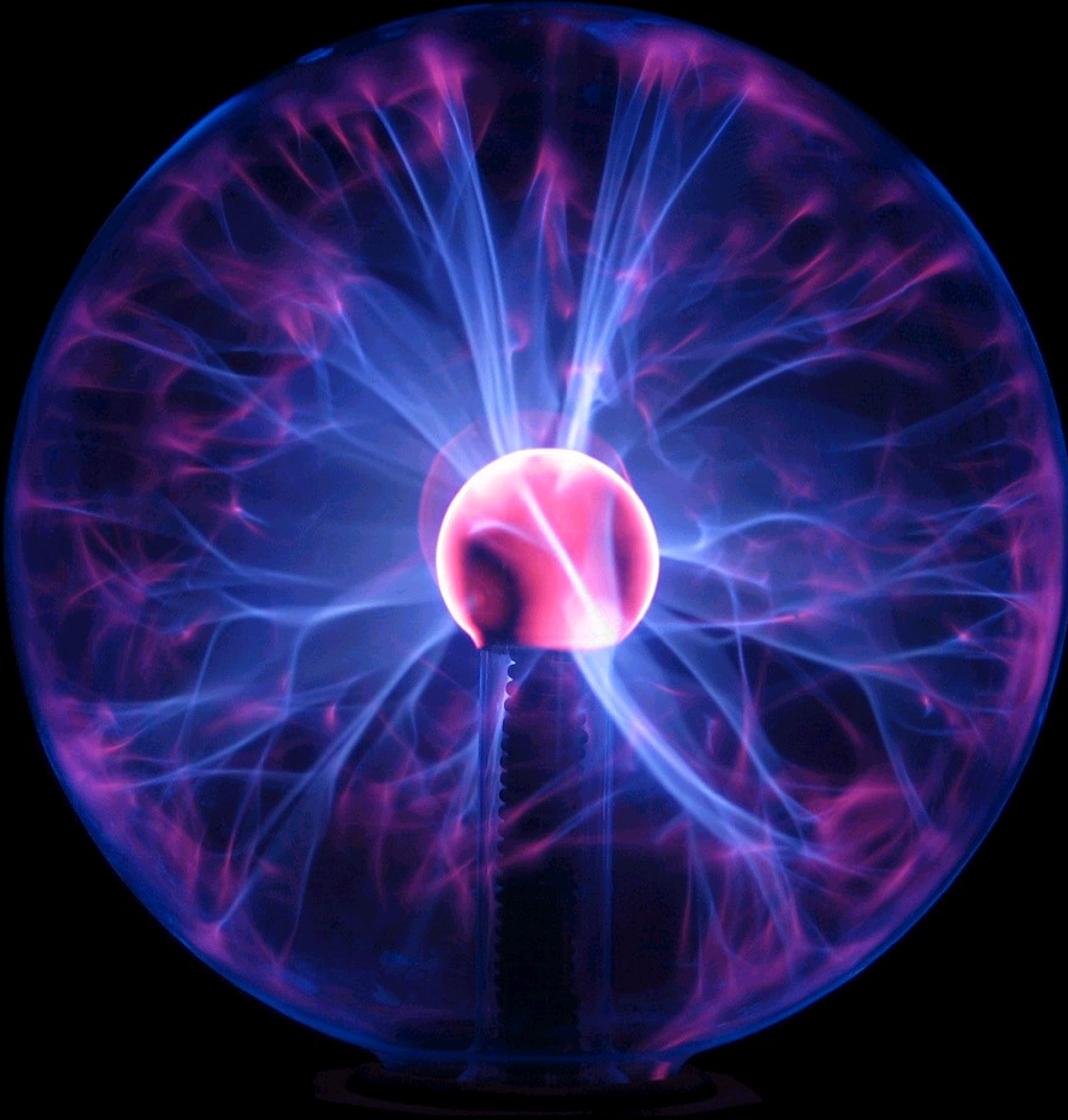
Temperature
Energy added

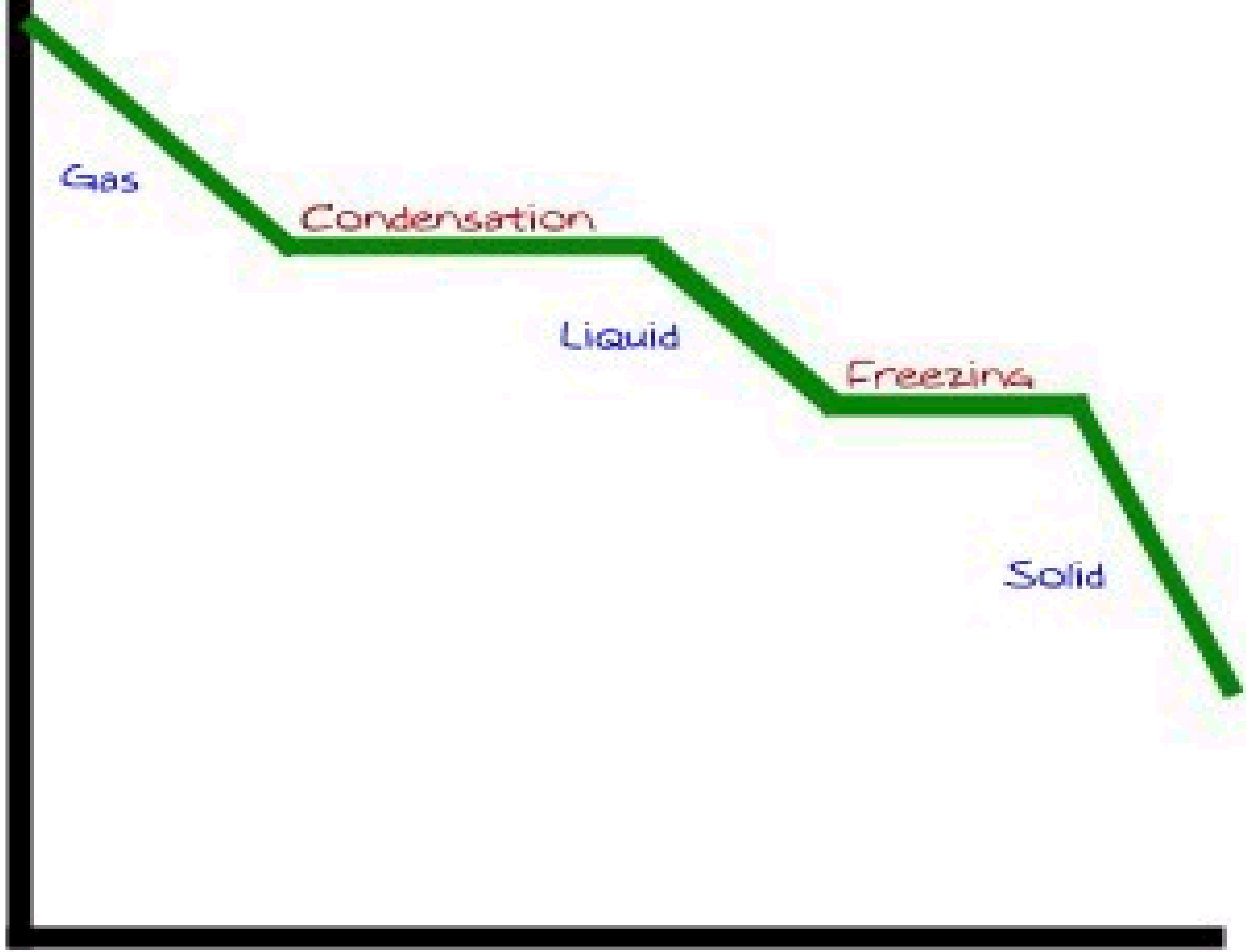
Change of State

- Chemical bonds have a corresponding energy:
  - Heat of fusion: how much energy is required to melt one kilogram of a material
  - Heat of vaporization: how much energy is required to vaporize one kilogram of a material

What's the difference between evaporation and boiling?






Gas
Condensation
Liquid
Freezing
Solid

Ex: how much heat to vaporize 250mL room temperature water given SLH=2260kJkg⁻1

- First, bring water to boiling point

$Q=mc\Delta T$

$Q=0.25(4180)80$

$Q=83.6kJ$

- Next, vaporization
- $Q=mL$
- $Q=0.25(2260)=565kJ$
- Total=649kJ

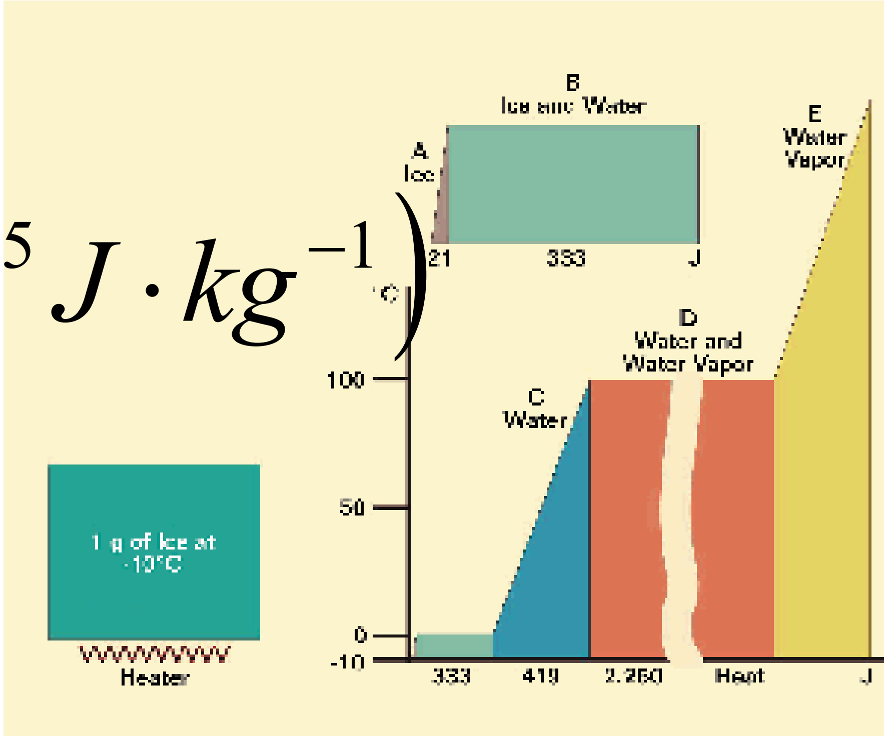
Do questions 12-14 p. 75

Phase Change

- Q=mL
- Ex: how much heat to melt a 5.5 kg block of ice?

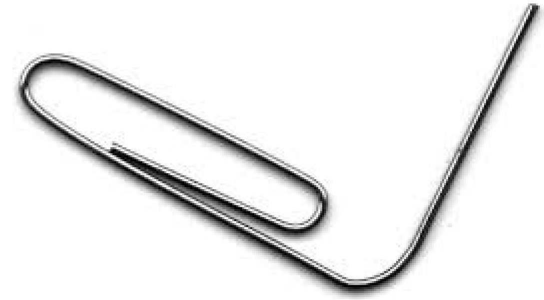
$$Q = 5.5kg\left(3.35\times10^{5}\,J\cdot kg^{-1}\right)$$

$$Q = 1.8MJ$$



- Try 12-14 p. 75
- Also finish q's p. 14-16 & p. 59-65

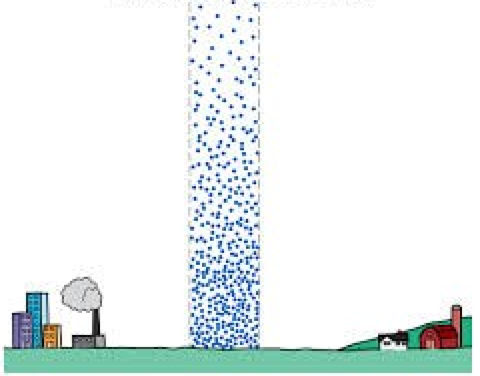
Pressure



- p=F/A
- Ex: how much pressure does a paper clip exert with its 1mm diameter tip with a force of 50 N?

$$p = \frac{F}{\pi r^2} = \frac{50}{\pi\left(5\times10^{-4}\right)^2} = 6.4\times10^{7}\,Pa$$

Pressure



- Ex: how much force does air pressure exert on the roof of our classroom?

$$F = P \cdot A = 1.01 \times 10^5 Pa(11m)10m$$

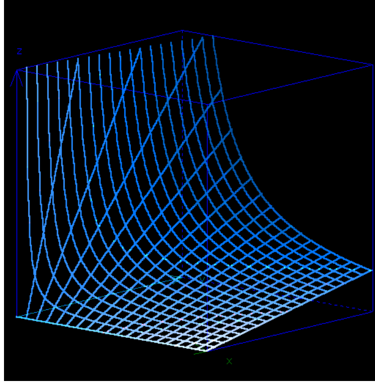
$$F = 1.1 \times 10^7 N$$

- Note: 1 Pascal=1N·m^{-2}

THERMODYNAMICS: Processes which cause energy changes as a result of heat flow to/from a system and/or work done by/on a system.

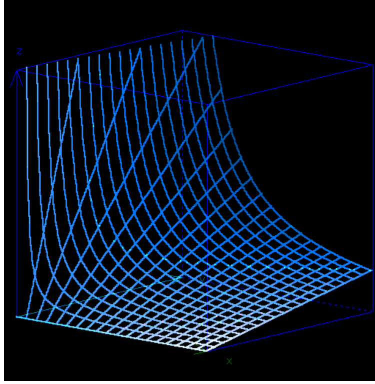
IDEAL GAS: The molecules obey Newton's laws; The intermolecular forces are negligible; The molecules are spherical with negligible volume; The motion of the molecules is random; The collisions are perfectly elastic; The time taken for a collision is negligible.

Ideal gas law

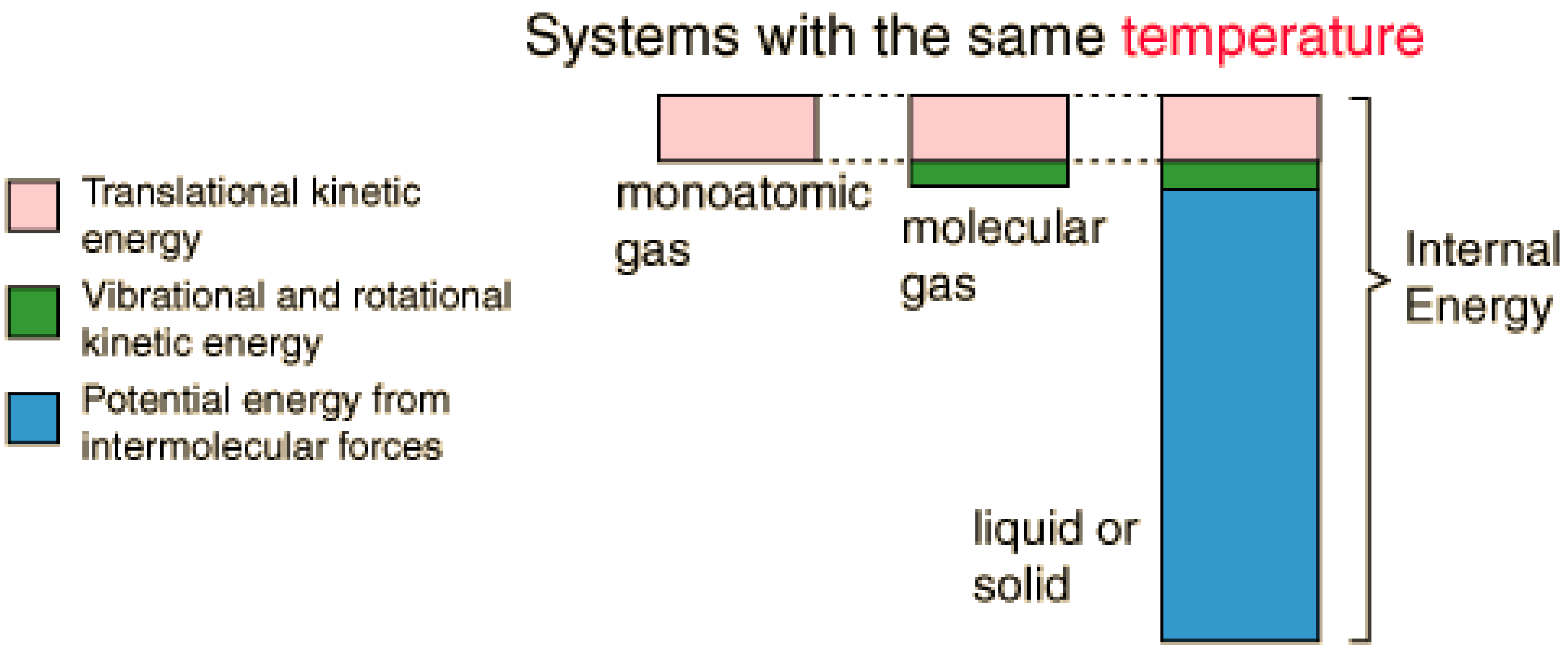


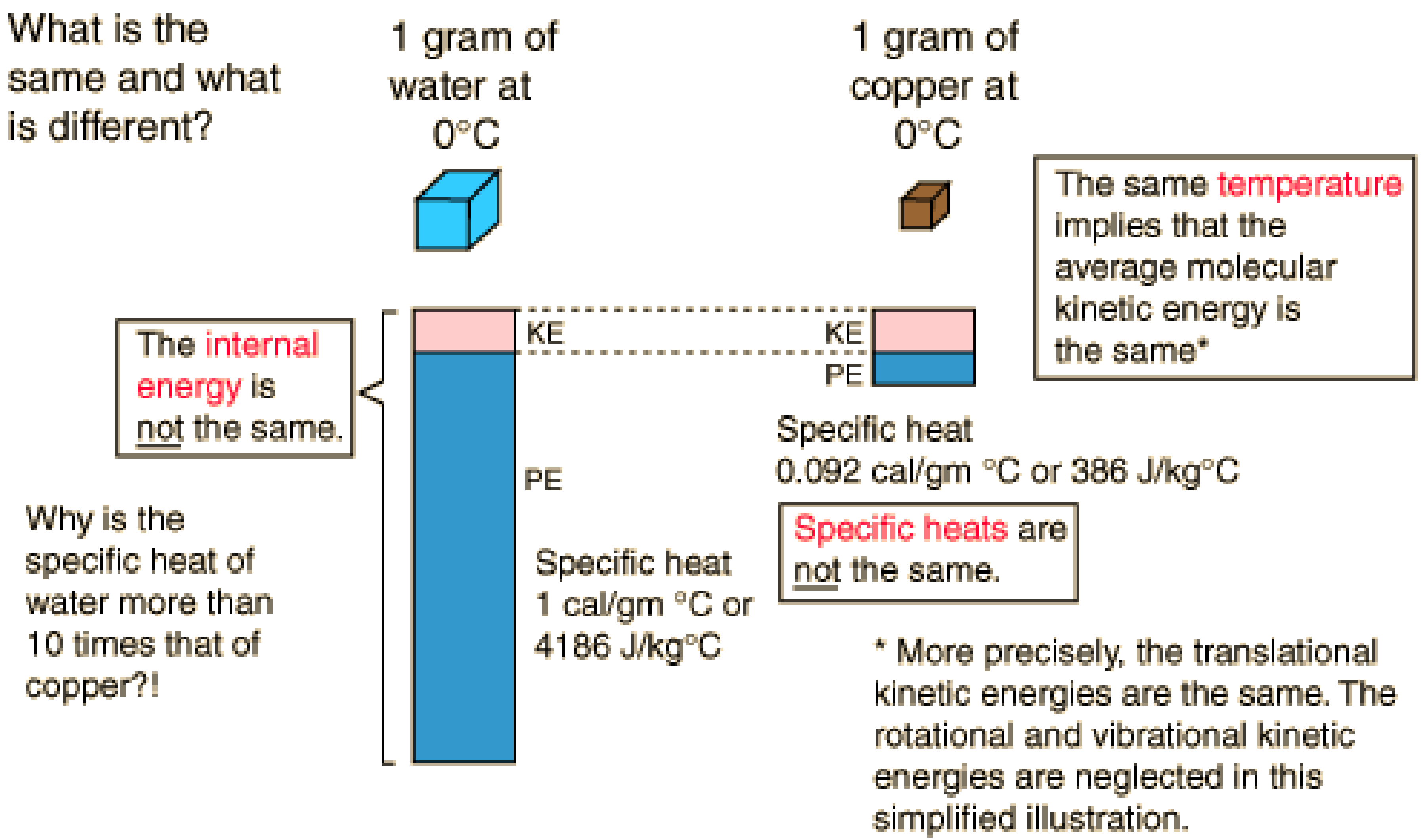
- Most gases behave like an ideal gas, as long as we are not at extremes of temperature or pressure
- Based on assumptions of spheres of negligible volume, intermolecular forces
- PV=nRT

Gas Properties PhET



- Open the Gas properties applet on PhET
- Choose two variables as your independent and dependent
- Collect data and graph (then share)
- PV=nRT


Systems with the same temperature
Translational kinetic energy
Vibrational and rotational kinetic energy
Potential energy from intermolecular forces
monoatomic gas
molecular gas
liquid or solid
Internal Energy


What is the same and what is different?
1 gram of water at 0°C
1 gram of copper at 0°C
The same temperature implies that the average molecular kinetic energy is the same*
The internal energy is not the same.
KE
PE
KE
PE
Specific heat 0.092 cal/gm °C or 386 J/kg°C
Specific heats are not the same.
Why is the specific heat of water more than 10 times that of copper?!
Specific heat 1 cal/gm °C or 4186 J/kg°C
* More precisely, the translational kinetic energies are the same. The rotational and vibrational kinetic energies are neglected in this simplified illustration.

ABSOLUTE ZERO OF TEMPERATURE: The lowest temperature possible. -273.16°C or zero kelvin (0K). The temperature at which the volume, pressure and kinetic energy of an ideal gas are zero.

KELVIN TEMPERATURE SCALE: Kelvin is the absolute thermodynamic temperature scale.

INTERNAL ENERGY: The energy contained in an object due to the random KE and PE of the molecules.

THERMAL ENERGY (HEAT): The non-mechanical transfer of energy between a system and its surroundings. Energy is only ‘heat’ if it is transferred.

Ex: Twice as hot?

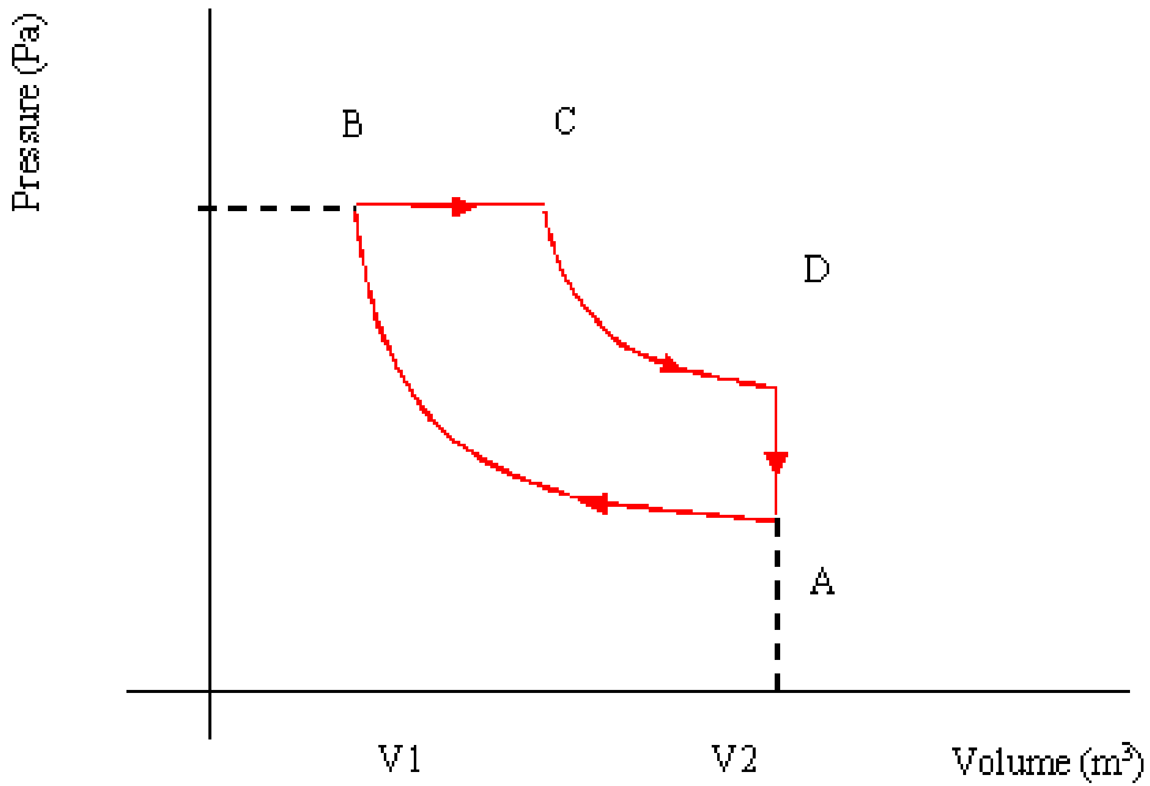
- What is the temperature of nitrogen gas with twice the kinetic energy as room temperature?
- We convert K=20 ºC +273
- Then double: 293x2=586K
- 586K-273=313 ºC

EQUATION OF STATE OF AN IDEAL GAS: Equation which is valid for an ideal gas and many real gases at low pressure. R is the universal molar gas constant (8.31 J mol^{-1} K^{-1})

$$PV = nRT$$

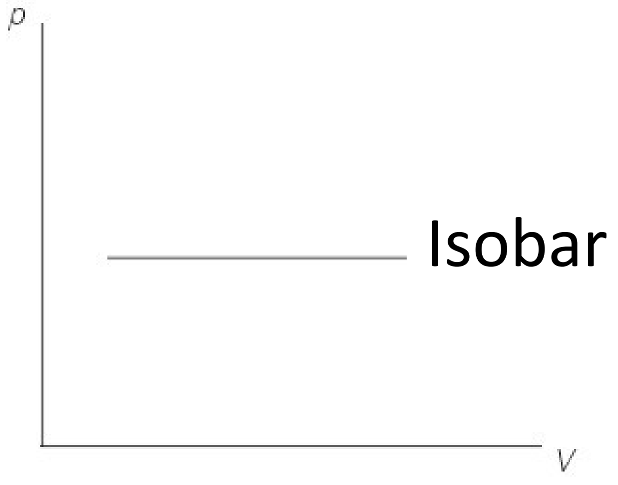
Do questions 15-18 p. 84

P-V DIAGRAMS: Also known as 'indicator diagrams'. The diagram shows how the pressure of a gas varies with its volume during a change. The work done (by or on the gas) is represented by the area under the graph.



Isobaric change

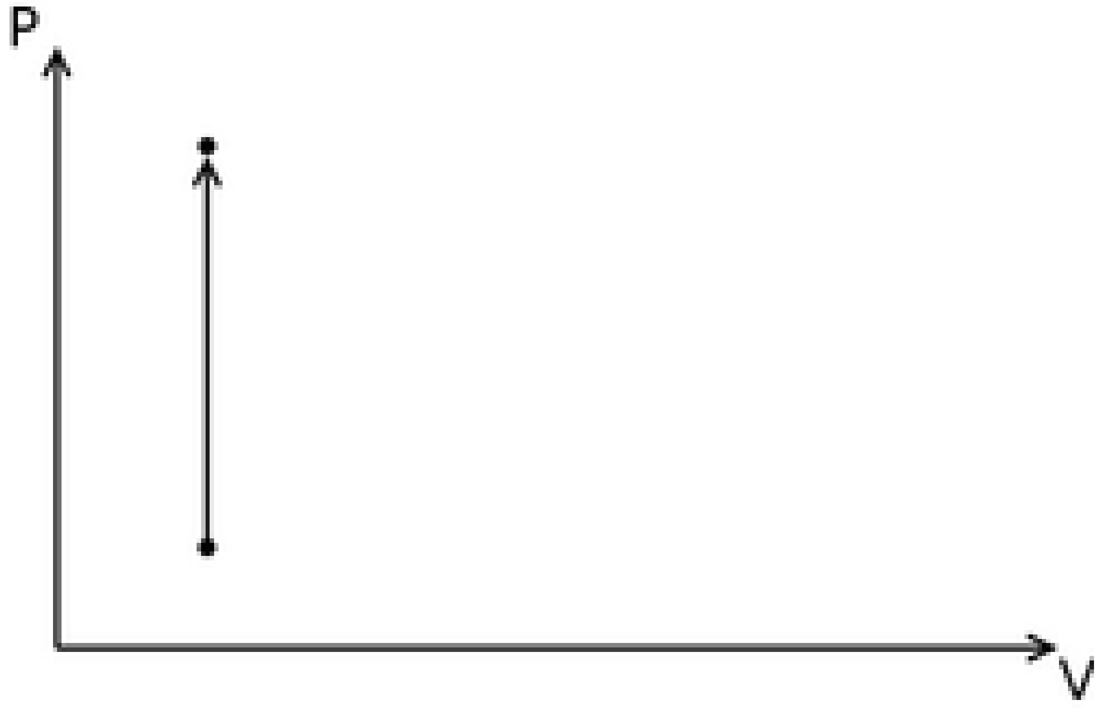
- Constant pressure



- $W = P\Delta V$

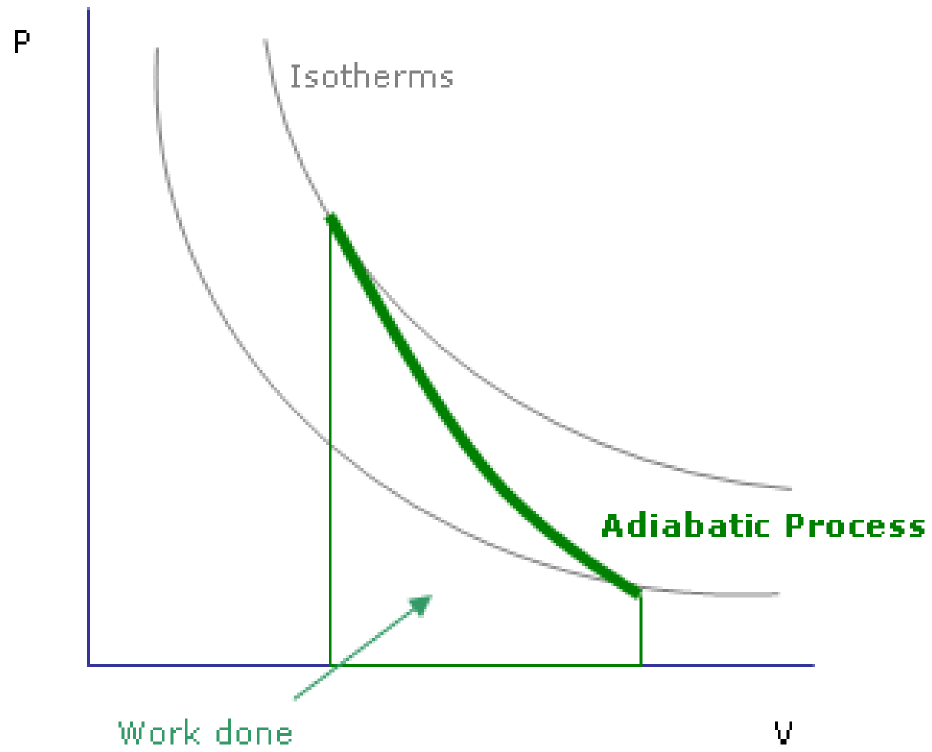
Isochoric change

- Constant volume



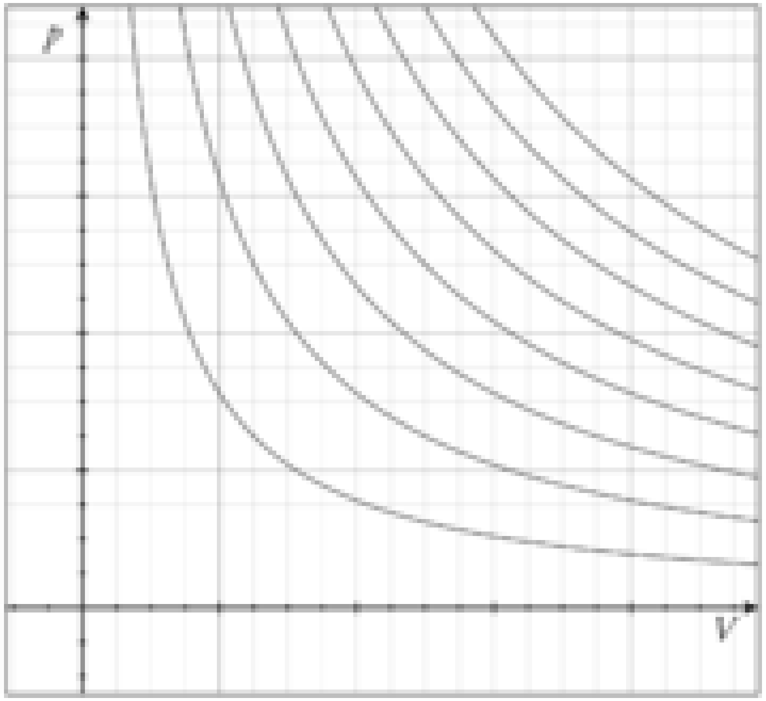
Adiabatic change

- No energy enters or leaves the system



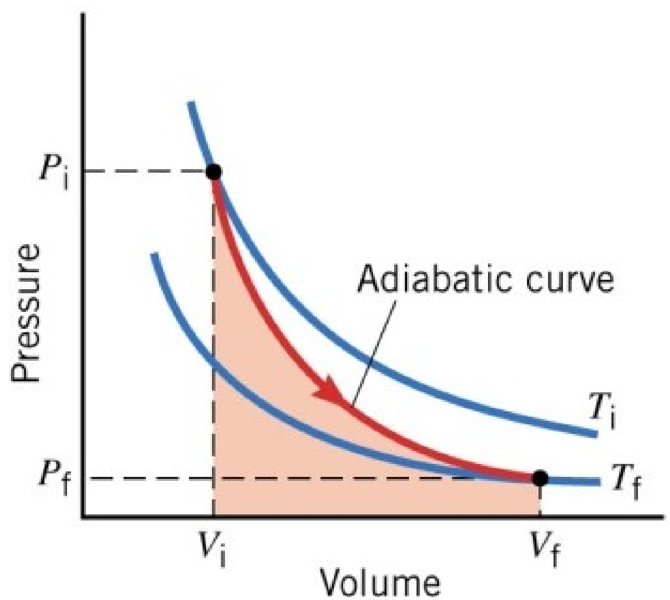
Isothermic change

- Constant temperature



Adiabatic changes

- No heat gained or lost



Do questions 19 p. 85

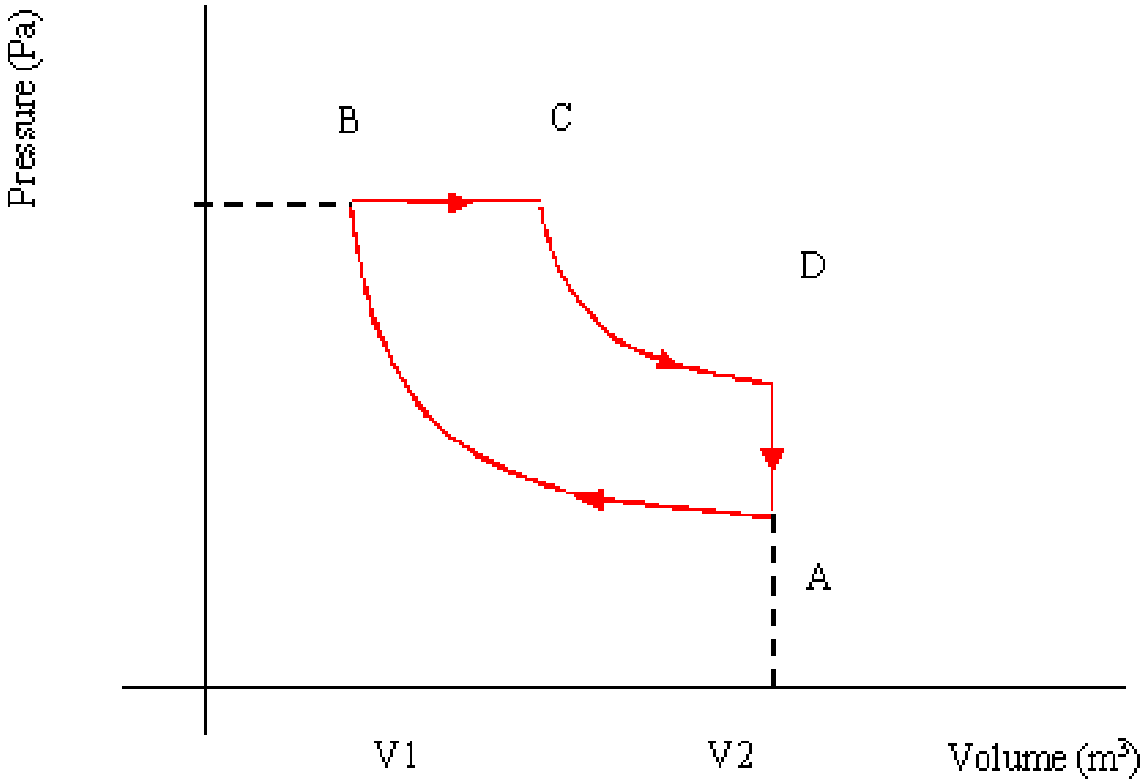
PHeT simulation: Gas properties

-collect data, how many of these changes can you graph? Save and email the spreadsheet with graphs

Engine cycles

- Work done in one segment = area under graph

- Total work done = area enclosed by graph



At temperature 290 K and pressure 4.8×10^5 Pa, the gas has volume 9.2×10^{-4} m^3.

(i) Calculate the number of moles of the gas. [

(ii) The gas is compressed isothermally to a volume of 2.3×10^{-4} m^3. Determine the pressure p of the gas. [

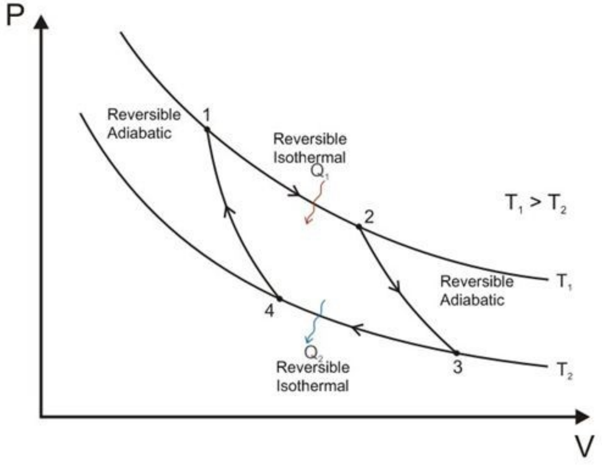
(iii) The gas is now heated at constant volume to a temperature of 420 K. Show that the pressure of the gas is now 2.8×10^6 Pa. [

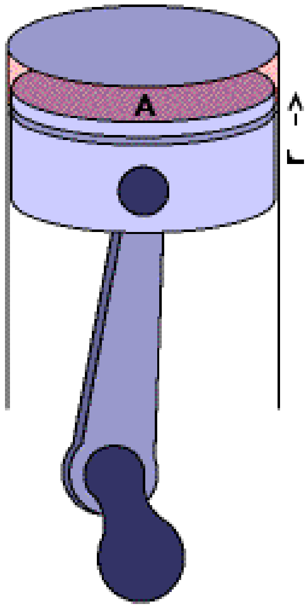
Finish questions 15-18 p. 84

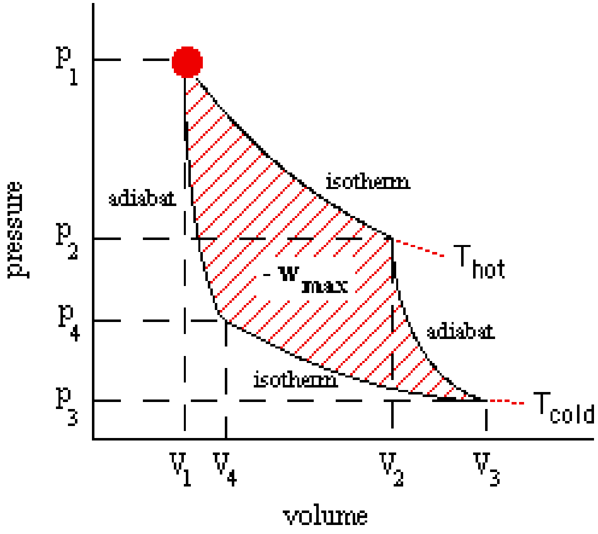
Do 19 p. 85

The Carnot cycle

- Assumes ideal gas

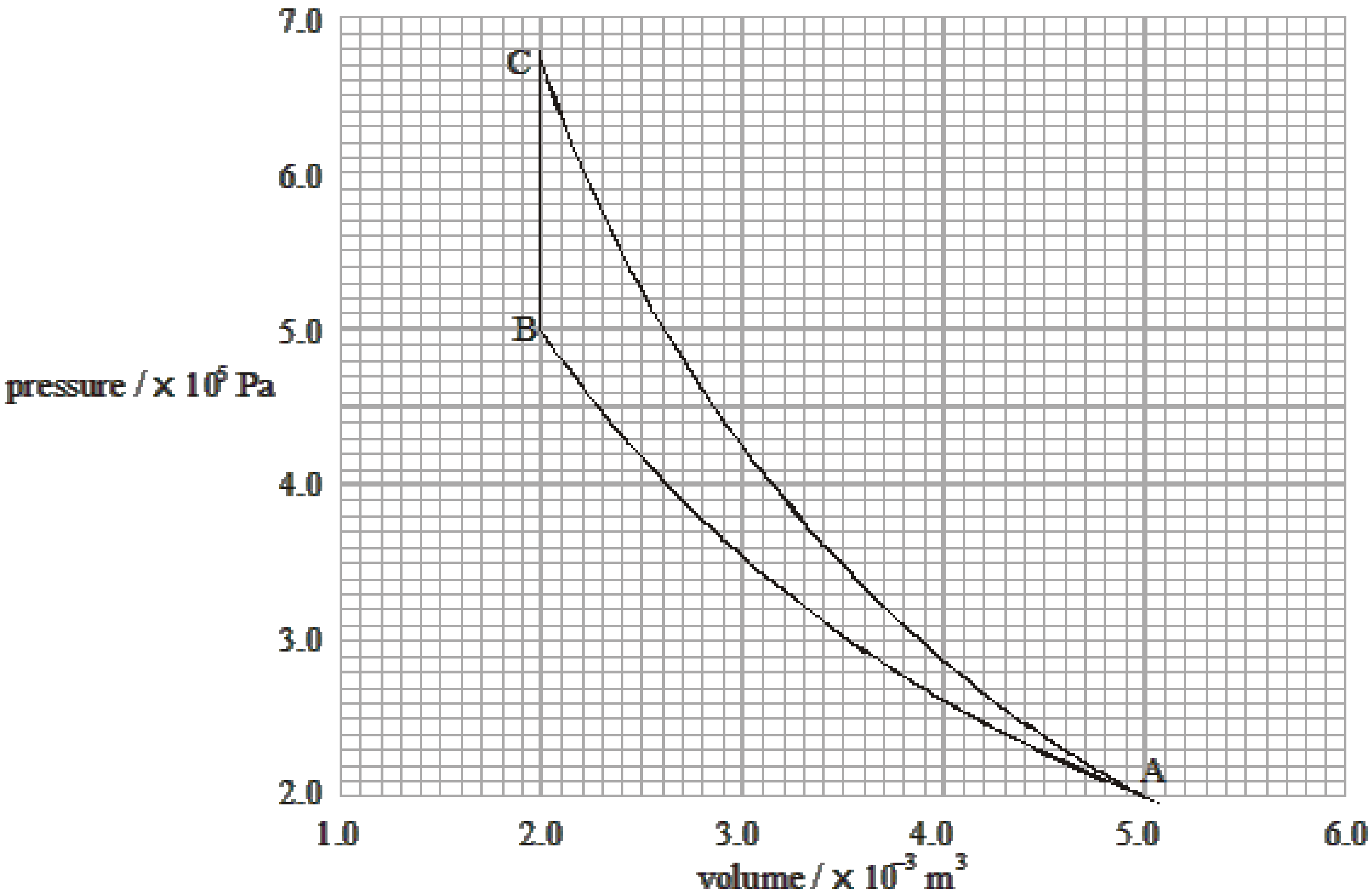




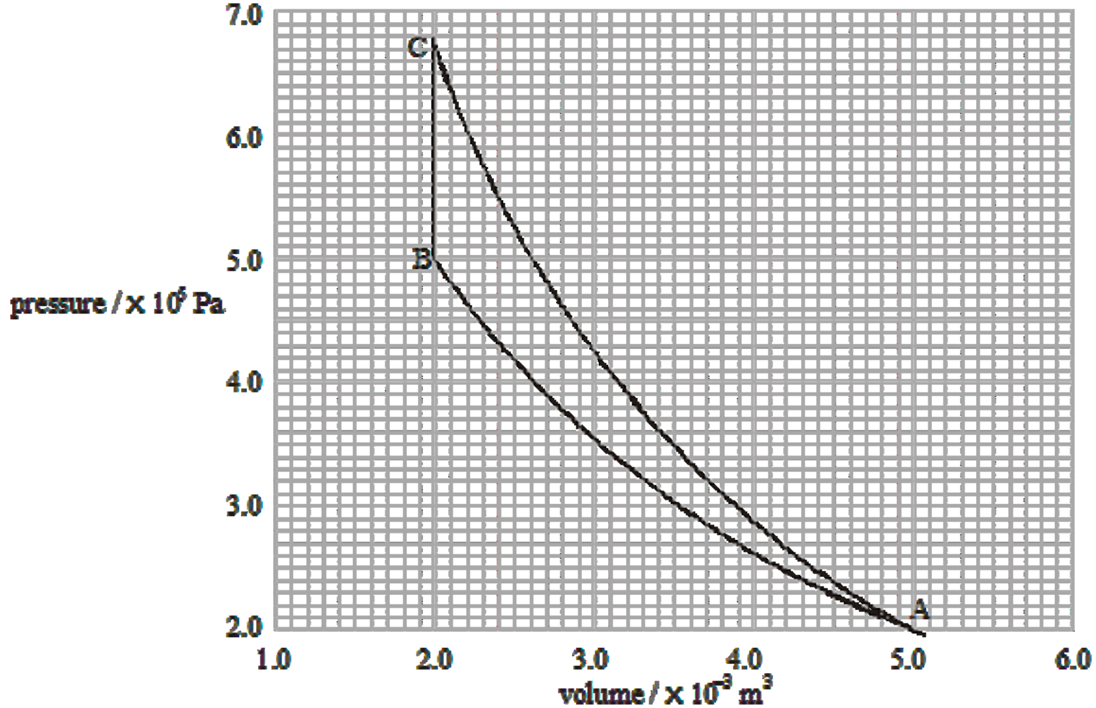


This question is about p–V diagrams.

The graph below shows the variation with volume of the pressure of a fixed mass of gas when it is compressed adiabatically and also when the same sample of gas is compressed isothermally.



- This question is about p–V diagrams.
- The graph below shows the variation with volume of the pressure of a fixed mass of gas when it is compressed adiabatically and also when the same sample of gas is compressed isothermally.



(a) State and explain which line AB or AC represents the isothermal compression.

(b) On the graph, shade the area that represents the difference in work done in the adiabatic change and in the isothermal change.

(c) Determine the difference in work done, as identified in (b).

(d) Use the first law of thermodynamics to explain the change in temperature during the adiabatic compression.

3. (a) *pV* constant for isothermal / adiabatic always steeper;
hence AB; 2

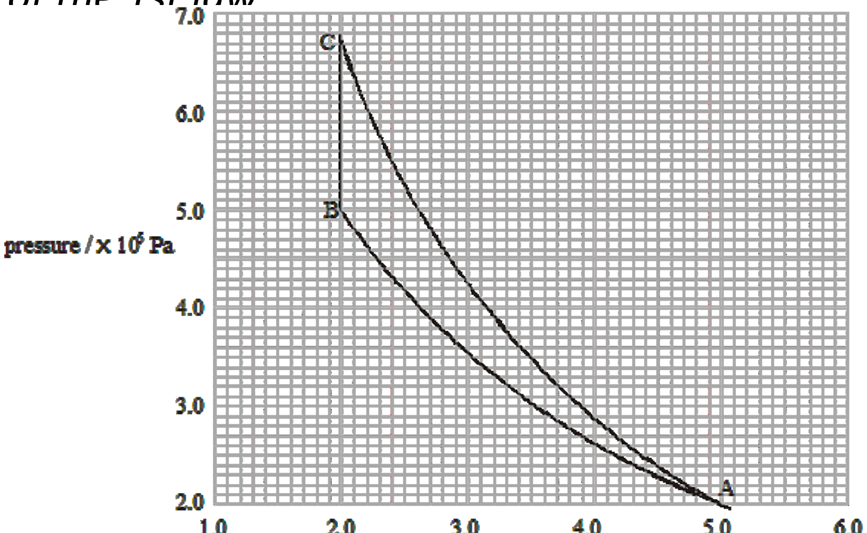
(b) area between lines AB and AC shaded; 1

(c) area is 150 (±15) small squares;
(allow ecf from (b))
work done = 1.5 × 1 × 10^–3 × 1 × 10^5;
= 150 J; 3

For any reasonable approximate area outside the range 150 (±15) squares award ***[2 max]*** *for the calculation of energy from the area.*

(d) no thermal energy enters or leaves / $\Delta Q = 0$;
so work done seen as increase in internal energy;
hence temperature rises; 3

Award ***[0]*** *for a mere quote of the 1st law*



FIRST LAW OF THERMODYNAMICS: The heat supplied to a mass of gas is equal to the increase in its internal energy plus the work done by the gas (expansion is positive work).

SYSTEM AND SURROUNDINGS: The fixed mass of gas which is under consideration can be called the ‘system’, the place to/from which heat flows is the ‘surroundings’.

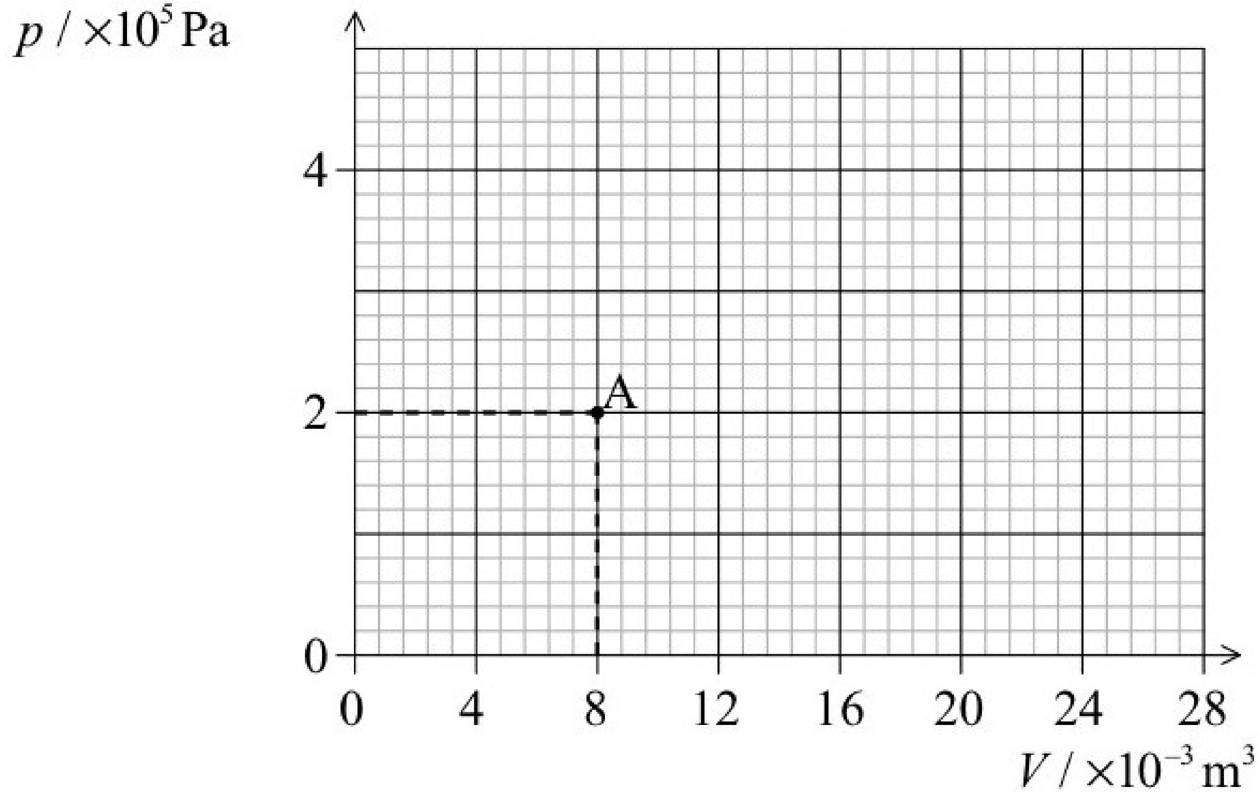
SECOND LAW OF THERMODYNAMICS: No continually working heat engine can take heat from a source and convert it completely into work.

OR: Thermal energy cannot spontaneously transfer from a region of low temperature to a region of high temperature.

OR: Although local entropy may decrease, the direction of a process is such as to increase the total entropy of the system and surroundings.

PRINCIPLE OF THE CONSERVATION OF ENERGY: Energy may be transformed from one form to another, but it cannot be created or destroyed ie the total energy of a system and its surroundings is constant.

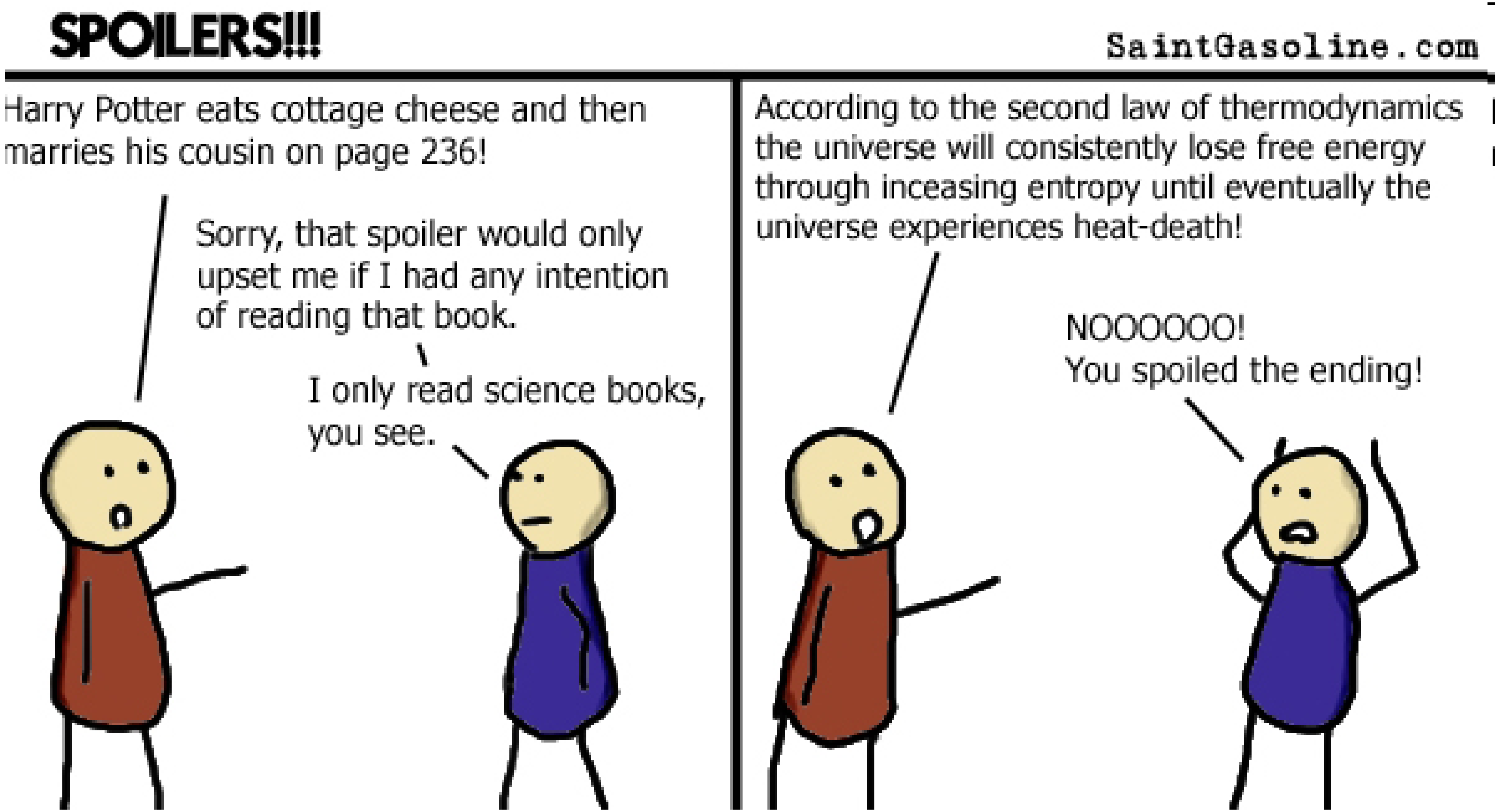
Point A in the *p*-*V* diagram below represents the state of an ideal gas.



The number of moles of the gas is 0.64.

(i) Deduce that the temperature of the gas in state A is approximately 300 K.

Laws of Thermodynamics



SPOILERS!!!
SaintGasoline.com
Harry Potter eats cottage cheese and then marries his cousin on page 236!
Sorry, that spoiler would only upset me if I had any intention of reading that book.
I only read science books, you see.
According to the second law of thermodynamics the universe will consistently lose free energy through inceasing entropy until eventually the universe experiences heat-death!
NOOOOOO! You spoiled the ending!

The Laws of Thermodynamics

0. Two bodies in thermal equilibrium are at same T

1. Energy can never be created or destroyed.

$$\Delta E = q + w$$

2. The total entropy of the UNIVERSE (= system plus surroundings) MUST INCREASE in every spontaneous process.

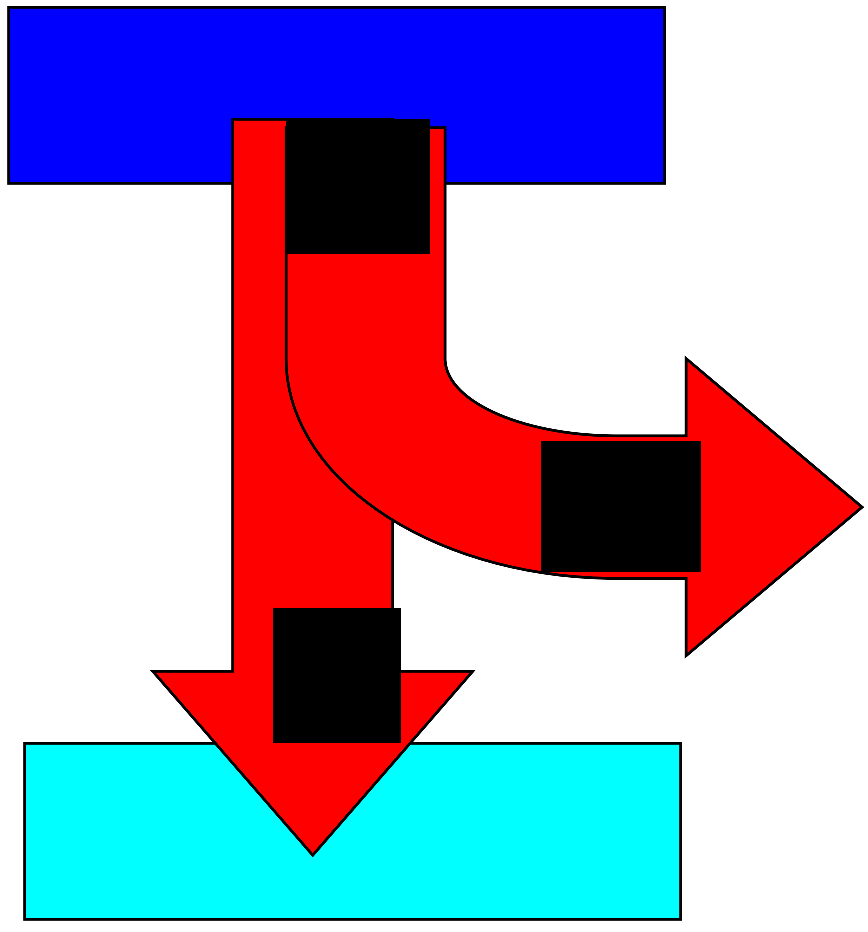
$$\Delta S_{TOTAL} = \Delta S_{system} + \Delta S_{surroundings} > 0$$

3. The entropy (S) of a pure, perfectly crystalline compound at T = 0 K is ZERO. (no disorder)

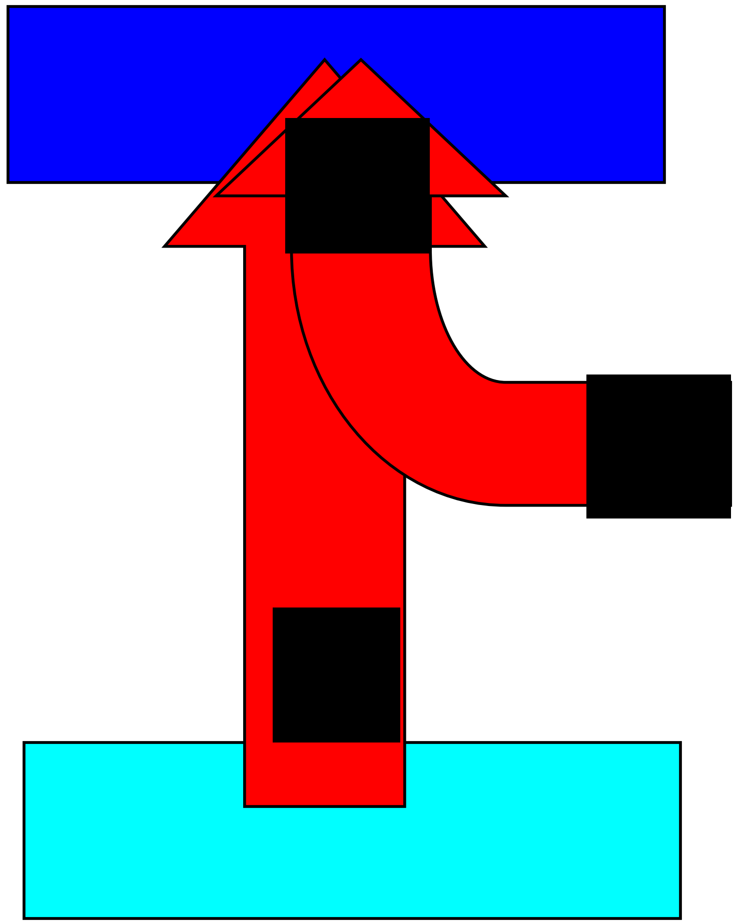
$$S_{T=0} = 0 \text{ (perfect xll)}$$

Heat Engine

$Q = \Delta U + W$



Heat Pump



$Q=\Delta U+W$

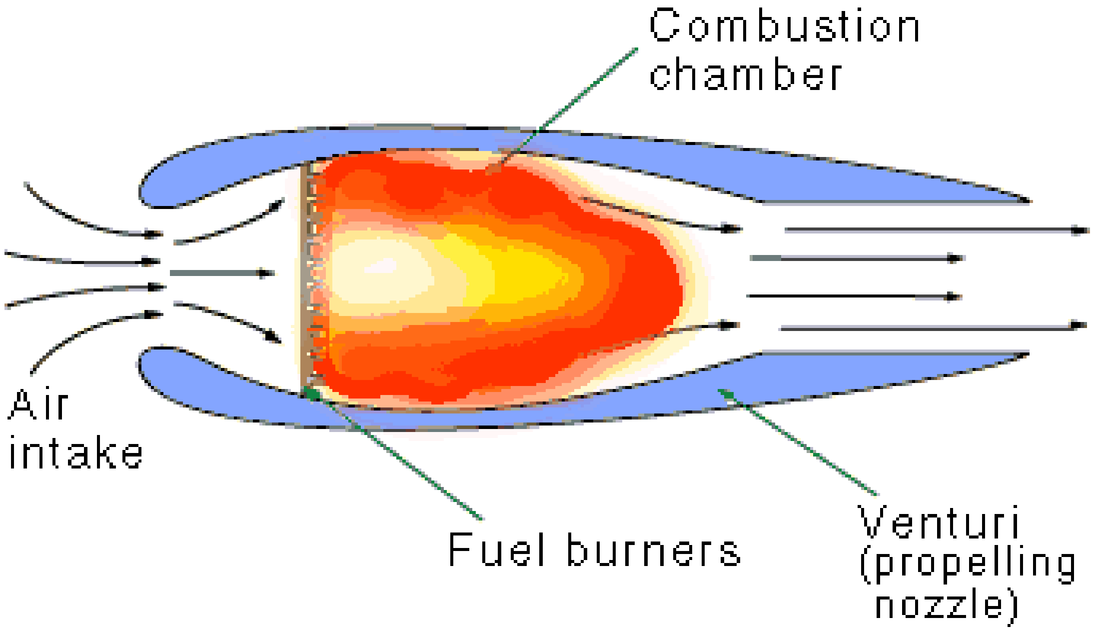
How does a waterwheel work?

- Water naturally flows from high to low
- We can use this to get work out
- If we want to pump the water uphill, we need to put in energy

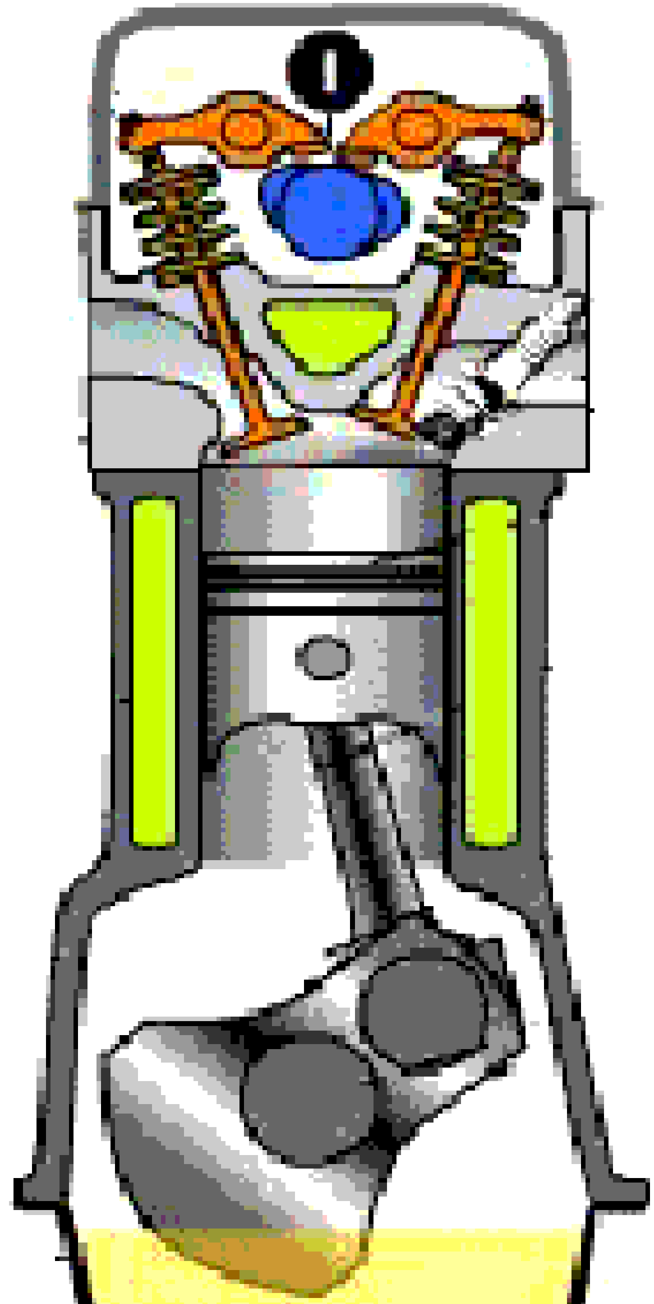
Heat Engines

- Heat tends to flow from areas of high temperature to low temperature
- We can use this to get energy out

- Like a waterwheel, the greater the difference, the more energy we can extract.


Combustion
chamber
Air
intake
Fuel burners
Venturi
(propelling
nozzle)


GAAR, SCOTT & Co.



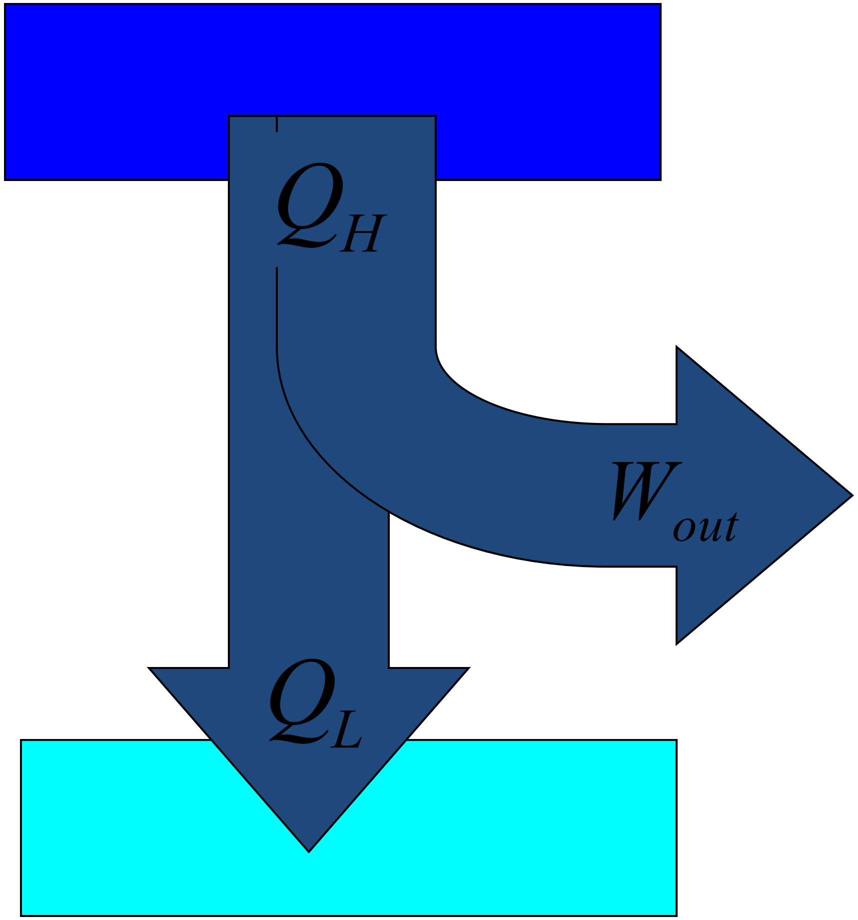
Heat pump?

- If we want heat to flow from cold to hot, we must *supply* work in
- This is the first law of thermodynamics

$$W + Q_L \stackrel{?}{=} Q_H$$

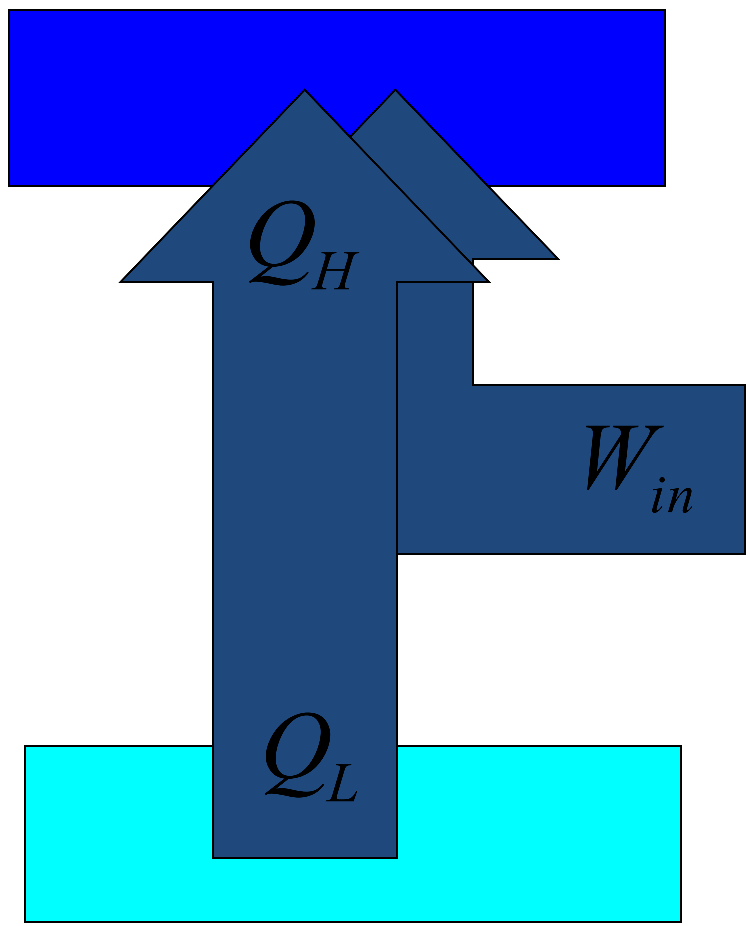
$$Q_H \overset{?}{=} W + Q_L$$

Heat Engine



$$Q_H \stackrel{\tau}{=} W + Q_L$$

Heat Pump



Do 20-21 p. 89

Add #22-23 p. 91*

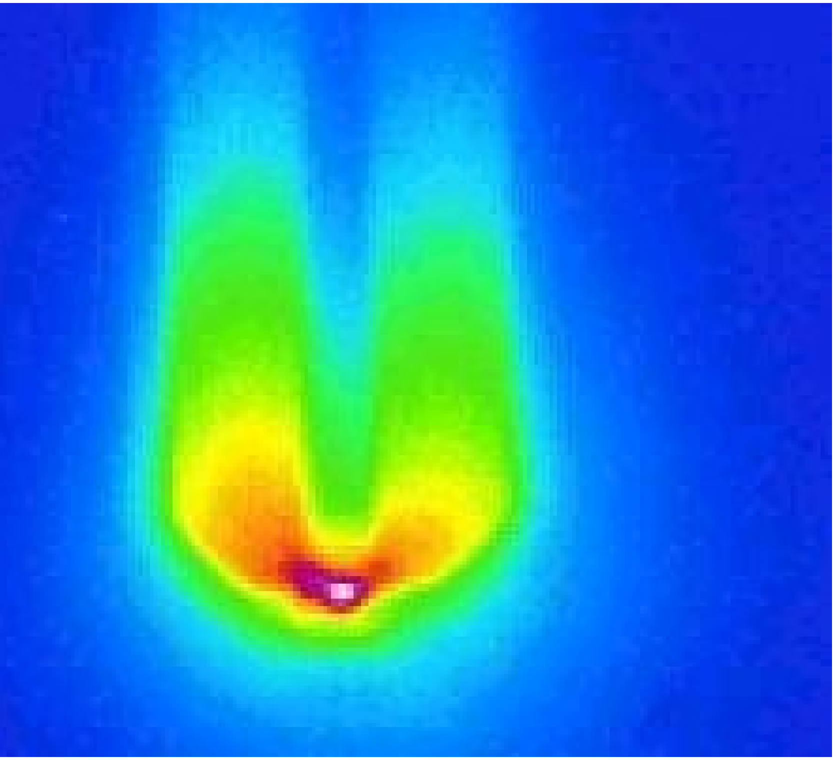
Read up to p. 94

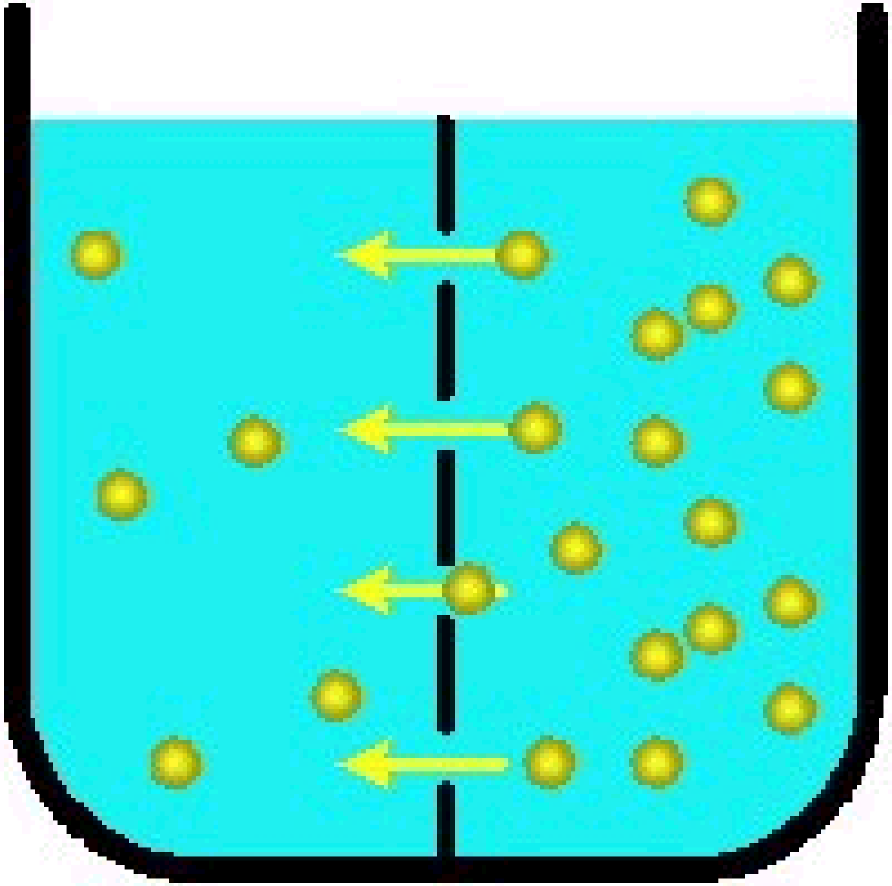
Entropy

- The universe is like a teenager: it loves creating disorder, or “entropy”
- The 2^{nd} law of thermodynamics:
  - The entropy of the universe is always increasing
  - Even processes that decrease the entropy of one object still cause total entropy to increase
- This can be seen as a cause for an “arrow” of time

Can you prove a video is not reversed?

- “What song is this”





Diffusion

(Solvent moves by concentration gradient)

Entropy

- This works for
  - Phase change
  - Chemical reactions
  - Gravity?
  - Demolition,
  - Collisions
  - Misc.

Entropy