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AP EXAM 2020

Notes

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AP Physics 2 2020 Exam Review

A College Board and COVID-19 Partnership Trademarked: CED

1: Fluids

1.0: Relevant Equations

Definition of Pressure

$P = F/A$ where F = force in newtons
A = surface area in m^2

Density

$\rho = m/V$ V = volume in m^3
m = mass in kg

Pressure in a Static Column of Fluid

$P = P_0 + \rho g h$

P = pressure in pascals
P_0 = pressure acting on the surface of the fluid
ρ = density in kg/m^3
g = acceleration due to gravity
h = height of the column of fluid above the point where pressure is being determined

Buoyancy Force

$F_b = \rho V g$

ρ = density of the displaced fluid in kg/m^3
V = volume of the displaced fluid in m^3

Continuity Equations

$A_1 v_1 = A_2 v_2$

A = the cross-sectional area of the pipe or flow tube in m^2
v = fluid velocity in m/s

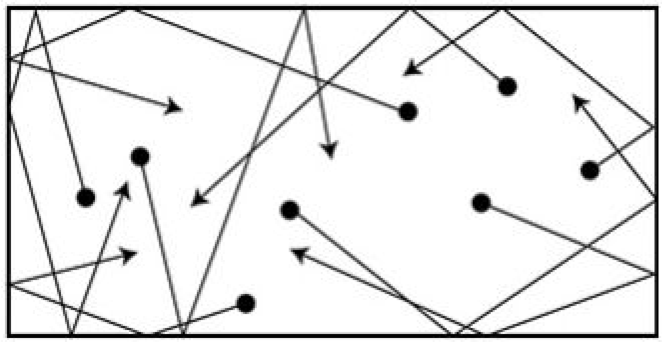
$\Delta V/t = Av$ $\Delta V/t$ = volumetric flow rate in m^3/s
$\Delta m/t = \rho A v$ $\Delta m/t$ = mass flow rate in kg/s
ρ = density of the fluid in kg/m^3

Bernoulli's Equation

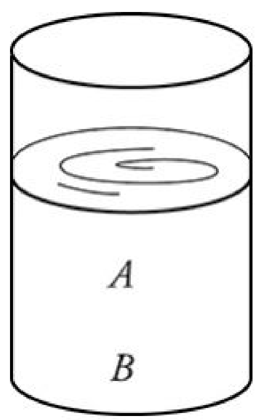
$$P_1 + \rho g y_1 + \tfrac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \tfrac{1}{2}\rho v_2^2$$

y = the height of a position in a column of fluid in meters

1.1: Fluid Systems



- The above diagram shows the molecules colliding with the walls of a container. Each collision imparts a small impulse on the wall.
- Because of the large number of random collisions that occur in every direction, any parallel forces to the wall exerted by the collisions will cancel out! However, the perpendicular component of the collision forces will not cancel out.
- This means that the forces caused by fluid pressure will always be perpendicular to the surface the fluid is in contact with.



- The above diagram shows a stationary liquid in a glass. Since the liquid is stationary, it must be in equilibrium, which means the forces all must be canceling out. Now consider points A and B in the liquid. At each point the forces must cancel out so that they can remain stationary. Each point must support the weight of all the fluid above itself with a counteracting force upward in order to maintain equilibrium.
- Point B has more atoms stacked on top of it than point A does. This means that the pressure from all those molecular collisions at point B must be greater than at point A simply because it has to support more fluid above itself in a gravitational field.
- Liquids have a much larger density than gases. Thus, the gravitational effect can cause a lot of the pressure in a liquid. Swim just 10 feet to the bottom of a pool and you will notice this pressure increase.

1.2: Density

- Density – The ratio of an object's mass to the volume it occupies:

$$\rho = M/V$$

*units of density = kg/m^3

- Specific Gravity – Specific gravity is the ratio of an object's density to the density of water:

$$SG = \rho / \rho_{water}$$

- If Specific Gravity is greater than 1, the object sinks. If SG is less than one, the object floats
- The weight of a fluid can be written as ρVg.

The value of the density of water in Physics 2 can be taken as 1000 kg/m3

1.3: Fluids - Pressure and Forces

- Pressure is defined as force per unit area

$$P = \frac{F}{A}$$

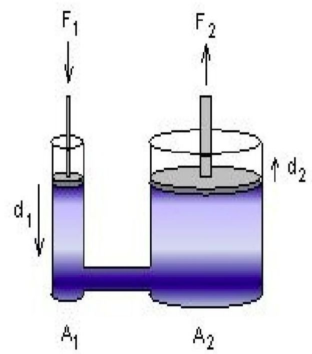
- It is measured in pascals (Pa). One pascal equals one newton per meter squared:
  - 1 Pa = 1 N/m2
- Absolute pressure is the pressure measured relative to a vacuum, and gauge pressure is the pressure measured relative to atmospheric pressure.

$$P_{absolute} = P_o + \rho gh \qquad P_{gauge} = \rho gh$$

- P0 is the initial pressure above the fluid, which is usually the atmospheric pressure of 1.01 x 10^5 Pa
- An absolute pressure of zero describes a complete vacuum. Therefore, absolute pressure equals gauge pressure plus one atmosphere:

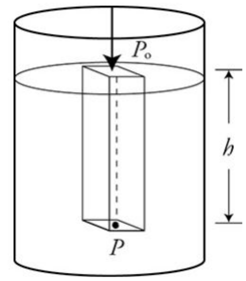
$$P_{Absolute} = P_{Gauge} + 100000 \text{ Pa}$$

1.4: Fluids and Free-Body Diagrams

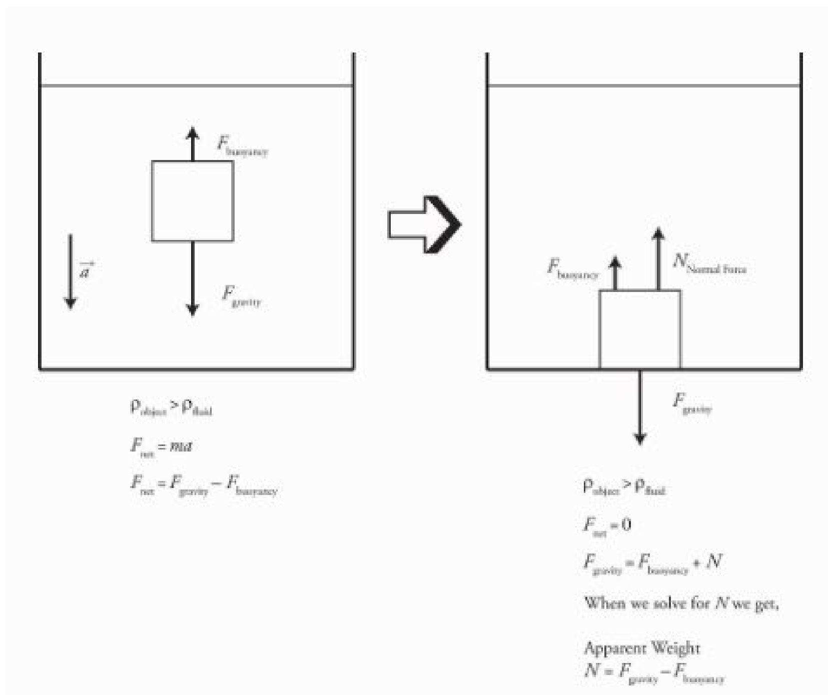


$$\frac{F_2}{A_2}=\frac{F_1}{A_1}+\rho g h$$

$P = P_0 + \rho g h$ where P = pressure
P_0 = pressure on the surface of the fluid
ρ = density in kg/m^3
g = acceleration due to gravity
h = height of the column of fluid above the point where pressure is being determined



- The upward force provided to an object wholly or partially immersed in a fluid is called the buoyant force. The buoyant force exists because fluid pressure is larger at greater depths.
- If a static liquid is exposed to atmosphere on both sides, pressure is the same on both sides, which is where Pascal's law as seen by the equation above applies
- Pascal's Principle states that any change in the pressure applied to a completely enclosed fluid is transmitted undiminished to all parts of the fluid and the enclosing walls.
- If a force is applied somewhere on a container holding a fluid, the pressure increases everywhere in the fluid, not just where the force is applied.



1.5: Buoyancy

Buoyant Force – Upward force on an object in a fluid; the buoyant force acts against gravity.

- An object will float if: The buoyant force is greater than the weight.
- When an object floats, the upward buoyant force on the object is greater than the downward force due to gravity. There is a buoyant force because pressure increases with depth.

- Archimedes Principle- The upward buoyant force that is exerted on an object submerged in a liquid is equal to the weight of the liquid displaced by the object.

F(b) = mg
→ mass = density x displaced volume
F(b) = ρ gVdisplaced

*An object floats if its density is less than the liquid.

1.6: Conservation of Energy in Fluid Flow

- Bernoulli's Equation is derived from applying conservation of energy to the flow of an ideal fluid:
- Going back to Physics 1, the change in energy is due to work done by outside forces. The work done on the fluid from the outside forces exerting pressure is equal to the total change in energy: Wnet = ΔK + ΔU
- The work done on each end of the fluid flow is: W = FΔx = (PA)Δx = PV
- The net work is then $W_{net} = P_1V - P_2V$ since both ends of the flow have forces in opposite directions.

*Fluid velocity is low where pressure is high and fluid velocity is high where pressure is low.

The change in kinetic energy is: $\Delta K = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2$
The change in potential energy is: $\Delta U = mgy_2 - mgy_1$

The work energy relationship is then:

$$P_1V - P_2V = \frac{1}{2}mv_2^2 - \frac{1}{2}mv_1^2 + mgy_2 - mgy_1$$

Since $\rho = mV$, dividing the entire equation by volume yields:

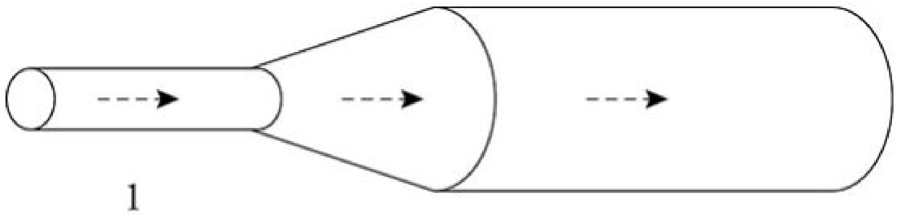
$$P_1 - P_2 = \frac{1}{2}\rho v_2^2 - \frac{1}{2}\rho v_1^2 + \rho g y_2 - \rho g y_1$$

$$\rightarrow \boldsymbol{P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2}$$

1.7: Conservation of Mass Flow Rate in Fluids

- Conservation of mass leads us to the continuity equation. Frequently the continuity equation will be needed to determine the speed of a fluid moving through a pipe of changing cross sectional area. Keep in mind that the continuity equation can be altered to give mass flow rate and volumetric flow rate

$$A_1 v = A_2 v$$



2: Thermodynamics

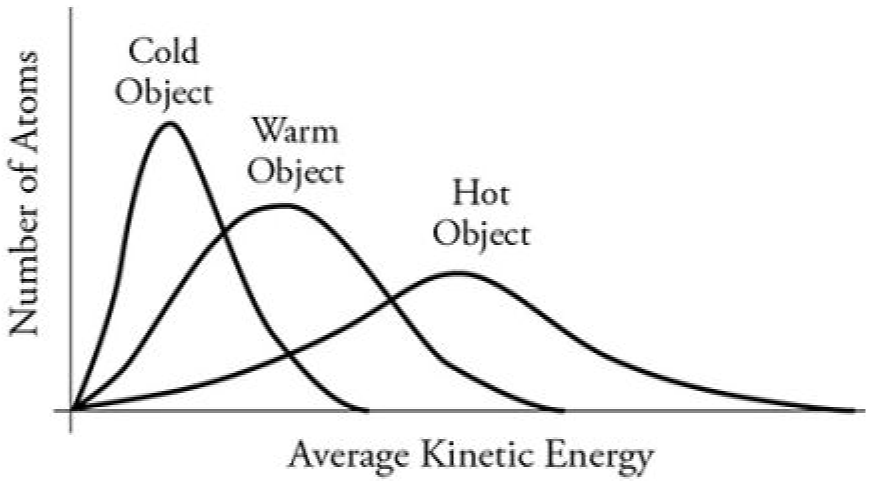
2.0: Relevant Equations

Ideal gas law:	$PV = nRT = Nk_BT$
Internal energy of an ideal gas:	$u = \frac{3}{2}nRT = \frac{3}{2}Nk_BT$
Average kinetic energy of the molecules in a gas and kinetic energy equation from mechanics:	$K_{average} = \frac{3}{2}k_BT$ and $K = \frac{1}{2}mv^2$
RMS speed of a gas molecule:	$v_{rms} = \sqrt{\frac{3k_BT}{m}}$
First law of thermodynamics:	$\Delta U = Q + W$
Work done by a gas:	$W = -P\Delta V$
Rate of heat transfer:	$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$

2.1: Thermodynamic Systems

- Thermodynamic System: a body of matter and/or radiation that is distinctly separated from its surroundings
- The properties of various systems depends on the chemical makeup of these systems

- The system is the collection of objects upon which attention is being focused. Everything else in the environment is called the surroundings.
- The physical condition of the system is called the state of the system. It includes pressure, volume, temperature, and mass of the system.
- The system and its surroundings must be separated by walls of some kind. Walls that permit the transfer of heat are called diathermal walls. Perfectly insulating walls that do not permit the flow of heat from the system to the surroundings are called adiabatic walls.



2.2: Pressure, Thermal Equilibrium, and the Ideal Gas Law

Ideal Gas Model Assumptions:

- Composition - A large number of particles travel in random directions at various speeds.
- Distance of Particles – Particles are far apart compared to their size.
- Attractive Force – Particles interact only in collisions (no attractive forces)
- Collisions – Collisions of particles with container walls are perfectly elastic.

Ideal Gas Law:

$$PV = nRT$$

R : Universal gas constant = 8.31 J/(mol x K)

$$PV = Nk_bT$$

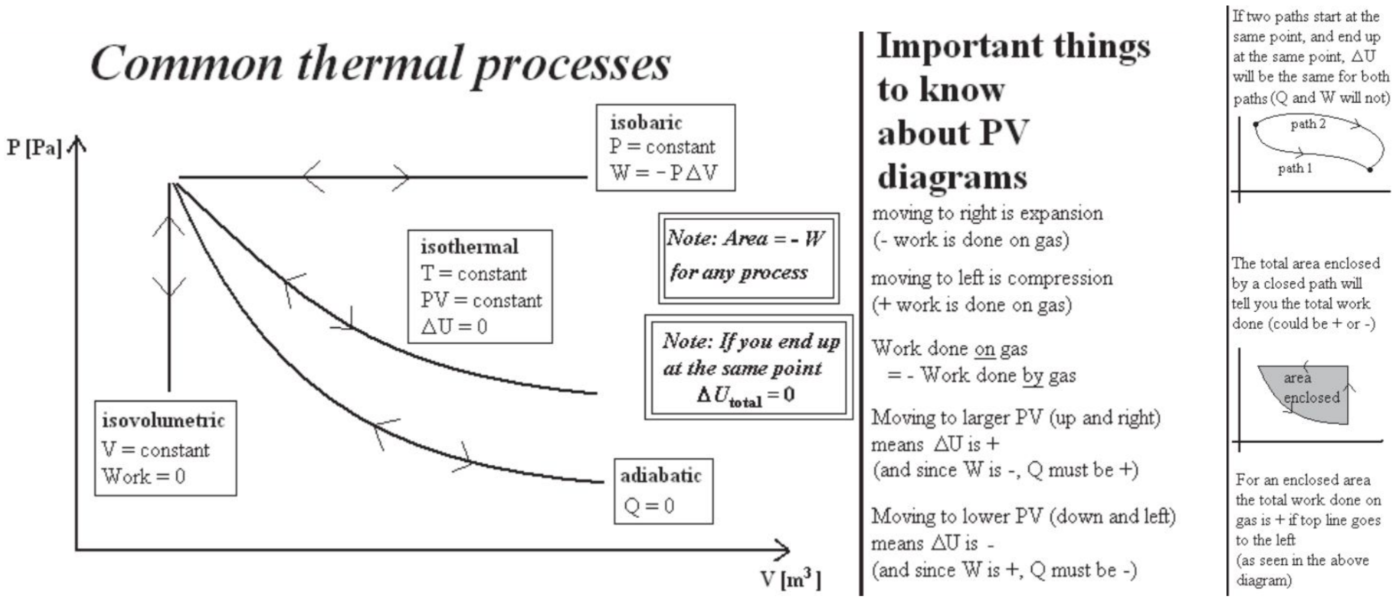
K : Boltzmann's constant = 1.38 x10^-23 J/K

2.3: Thermodynamics and Forces

- Pressure is the result of the molecules colliding with one another and with the sides of the container. It is defined as the force per unit area (P = F/A) on the walls of the container.

- The average kinetic energy of the gas molecules is related to the most likely speed a particle will be moving, but the particles in the gas will be moving with a large distribution of various speeds

2.4: Thermodynamics and Free-Body Diagrams



2.5: Thermodynamics and Contact Forces

The Laws of Thermodynamics

- *Zeroth Law:* Two systems individually in thermal equilibrium with a third system are in thermal equilibrium with each other. Objects in thermal equilibrium will have the same temperature.
  - When two objects are brought into contact, heat will flow from the warmer object to the cooler one until they reach thermal equilibrium.
- *First Law:* Energy (in the form of heat) is neither created nor destroyed in any thermodynamic system.

First Law: $\Delta U = Q_{\text{heat flows into gas}} + W_{\text{work done on gas}}$

- Internal energy (U) increases if heat Q flows into a gas, or work W is done on a gas
- If internal energy of a gas increases, then T increases.
- For Monatomic Ideal Gas you can use the equation $\Delta U = 3/2\, \Delta(PV)$

$$\Delta U = U_f - U_i = Q - W$$

  - Q is positive when the system gains heat
  - Q is negative when the system loses heat
  - W is positive when work is done by the system

- W is negative when work is done on the system
- Because internal energy depends only on temperature, ΔU is determined once the initial and final temperatures are known. Internal energy depends only on the state of a system, not on the method by which the system arrives at a given state.

- *Second Law:* The entropy of the universe increases in all natural processes.

efficiency = $W/Q_H = 1 - Q_C/Q_H$ (Q_c is waste heat created by heat engine)

- The most efficient engine (Carnot engine) has efficiency of **$e = 1 - T_C/T_H$**

- *Third Law*: It is not possible to lower the temperature of any system to absolute zero in a finite number of steps.

2.6: Heat and Energy Transfer

- Energy is spontaneously transferred from high-temperature systems to low-temperature systems.
- Flow of energy between systems of different temperatures is called heat (an object cannot "have" heat).
- Heat flow may occur through 3 processes: conduction (direct contact of surfaces), convection (through a fluid), and radiation (as a wave).
- Energy is transferred as kinetic energy from faster moving particles to slower moving particles.

$Q_{gained} = Q_{lost}$ (note: Heat is measured in Joules)

$Q = mc\,\Delta T$ (use when object is changing temperature)

$Q = mL$ (use when object is changing phase, e.g. solid to liquid or liquid to gas)

- use **heat of fusion** for (solid <-> liquid) use **heat of vaporization** for (liquid <-> gas)

2.7: Internal Energy and Energy Transfer

- Changes in the structure of a system (such as its volume) results in a change in its internal energy.
- Internal energy includes kinetic energy and potential energy in the motion and configuration of the objects in the system.
- Energy can be transferred into/out of a system through external forces doing work on the system, or through heat.
- The change in system energy is always equal to the work done and heat. (i.e. U= Q+W).

2.8: Thermodynamics and Elastic Collisions - Conservation of Momentum

- Linear momentum is conserved in collisions between objects.
- In elastic collisions, the kinetic energy of the closed system after the collision is the same as it was before.

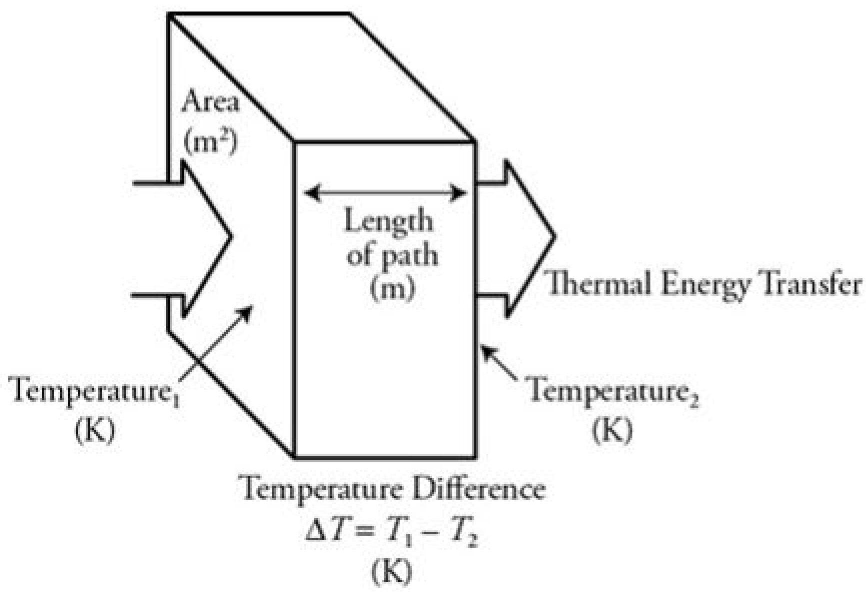
- When two objects have the same temperature, they are in thermal equilibrium and the net heat transfer between them is zero.

2.9: Thermodynamics and Inelastic Collisions - Conservation of Momentum

- Linear momentum is conserved in collisions between objects.
- In inelastic collisions, the kinetic energy of the closed system after the collision is different from the kinetic energy before the collision.
- Happens between heat transfer of objects of differing temperatures (wml not be on test)

2.10: Thermal Conductivity

- Whenever two objects with different temperatures touch each other, heat will transfer from the hotter object to the colder one through atomic collisions until the objects reach the same temperature, or equilibrium.
- There are a couple of properties that can affect the rate of heat transfer:
  - The thermal conductivity, k, of the material. For example, metals tend to conduct heat better and will have a high thermal conductivity compared to nonmetals.
  - The difference in temperatures between the cold and hot objects, ΔT. A greater difference will produce a larger rate of heat transfer



- The cross-sectional area of the material the heat is being transferred along, A—the larger the cross-sectional area of contact, the greater the rate of heat transfer.
- The length, L, of the material the heat is being transferred through —a longer length, the lower the rate of heat transfer.

- The proportionality constant, k, is called the thermal conductivity of the material. Conduction happens best in metals because the free electrons in the metallic bonds transfer heat rapidly through the substance.

2.11: Probability, Thermal Equilibrium, and Entropy

- Entropy – Entropy is the measure of the disorder in a system. The change in entropy, ΔS, when heat is added to a system by a reversible process at constant temperature is given by:

$$\Delta S = QT$$

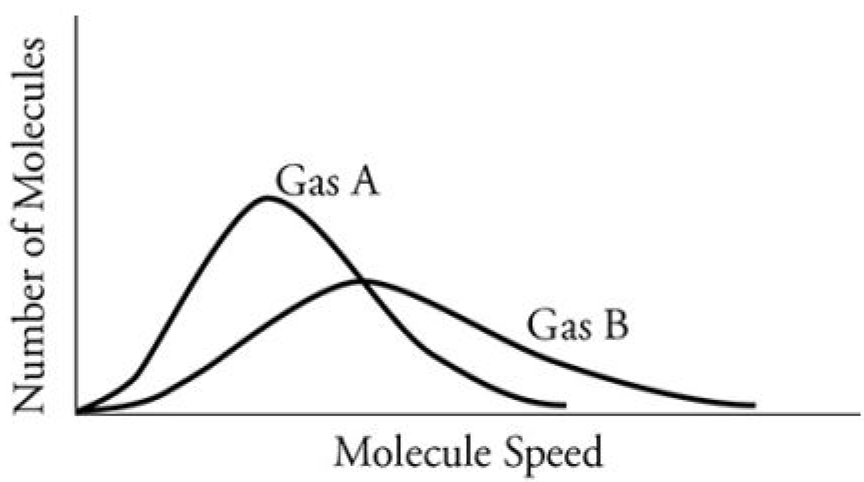
- The 2nd Law of Thermodynamics – The entropy of the universe increases in all natural processes. Heat never flows spontaneously from cold to hot.

*Work can be done to decrease entropy.
*A disorderly arrangement is more probable than an ordered one.

- Consequences:
  - It is impossible for thermal energy to flow from a cold to a hot object without performing work.
  - It is impossible, in a cyclic process, to completely convert heat into mechanical work.
- Thermal expansion:

$$\Delta L = \alpha L_o \Delta T \quad [m]$$

  - ΔT can be in C or K, but if you have an equation with just T it must be in K
  - Almost all objects expand when heated (even holes in objects expand as well)



3: Electric Force, Field and Potential

3.0: Relevant Equations

Electric force between two charged objects:	$\lvert\vec{F}_E\rvert = \frac{1}{4\pi\varepsilon_0}\frac{\lvert q_1q_2\rvert}{r^2}$ where r is the distance between the centers of the charges.
The relationship between electric force and electric field:	$\vec{E} = \frac{\vec{F}_E}{q}$
Electric field produced by a point charge:	$\lvert\vec{E}\rvert = \frac{1}{4\pi\varepsilon_0}\frac{\lvert q\rvert}{r^2}$
Change in electric potential energy:	$\Delta U_E = q\Delta V$
Electric potential produced by point charge:	$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$
The relationship equation between electric field and electric potential difference:	$\lvert\vec{E}\rvert = \left\lvert\frac{\Delta V}{\Delta r}\right\rvert$
Potential difference between two charged plates of a capacitor:	$\Delta V = \frac{Q}{C}$
Capacitance of a parallel plate capacitor:	$C = \kappa\varepsilon_0\frac{A}{d}$
Electric field strength between charged plates of a parallel plate capacitor:	$E = \frac{Q}{\varepsilon_0 A}$
Electric potential energy stored in a charged capacitor:	$U_C = \frac{1}{2}Q\Delta V = \frac{1}{2}C(\Delta V)^2$

3.1: Electric Systems

- Systems are made up of their components.

3.2: Electric Charge

- Only two types of electrical charge, positive and negative
- Smallest is the elementary charge (one electron/proton)

- Like charges repel, opposite charges attract
- The magnitudes of proton and electron charges are 1.60 x 10^-19 C, being + and - respectively

3.3: Conservation of Electric Charge

- Objects interacting with each other in a system conserves charge
- During any process, the net electric charge of an isolated system remains constant.
- Usually electrons are transferred rather than protons, because they take less energy to move as they are on the outside of the atom.
- Separate neutral charges through induction (conductors)
- Grounding lets charges flow to the Earth

3.4: Charge Distribution - Friction, Conduction, and Induction

- Conduction charges through contact. If you touch a charged insulator, you will share the charge only right where you touched it because the rest of the charges on the object are locked in place.
- Friction can charge by placing two materials into contact that have a different pull on their outer electrons, and electrons start jumping from one object to the other. Rub the objects together and the process speeds up
- Charge by induction charges without contact→ changes charge distribution. An induced charge occurs when an electrically neutral object becomes polarized —when negative charges pile up in one part of the object and positive charges pile up in another part of the object.

3.5: Electric Permittivity

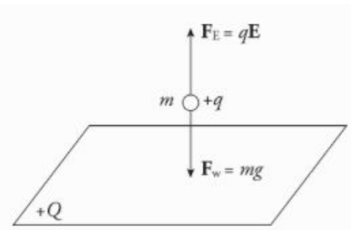
- Materials have a property of how much it allows electric fields through
- Affects the constants in the equations for electric field (ε_0)

3.6: Introduction to Electric Forces

- Electric Forces are vectors
- Forces are interactions between two objects
- $F_E = \frac{kqQ}{r^2} = \frac{qQ}{4\pi\varepsilon_0 r^2}$

3.7: Electric Forces and Free Body Diagrams

- Free body diagrams show the forces on one body
- Net force is a vector sum $\vec{F}_{net} = \sum_i^n \vec{F}_i$



Let q be the charge on the object. Then, in order for F_E to balance mg, we must have

$$qE = mg \quad \Rightarrow \quad q = \frac{mg}{E} = \frac{(5\times10^{-3}\ \text{kg})(10\ \text{N/kg})}{10^6\ \text{N/C}} = 5\times10^{-8}\ \text{C} = 50\ \text{nC}$$

3.8: Describing Electric Force

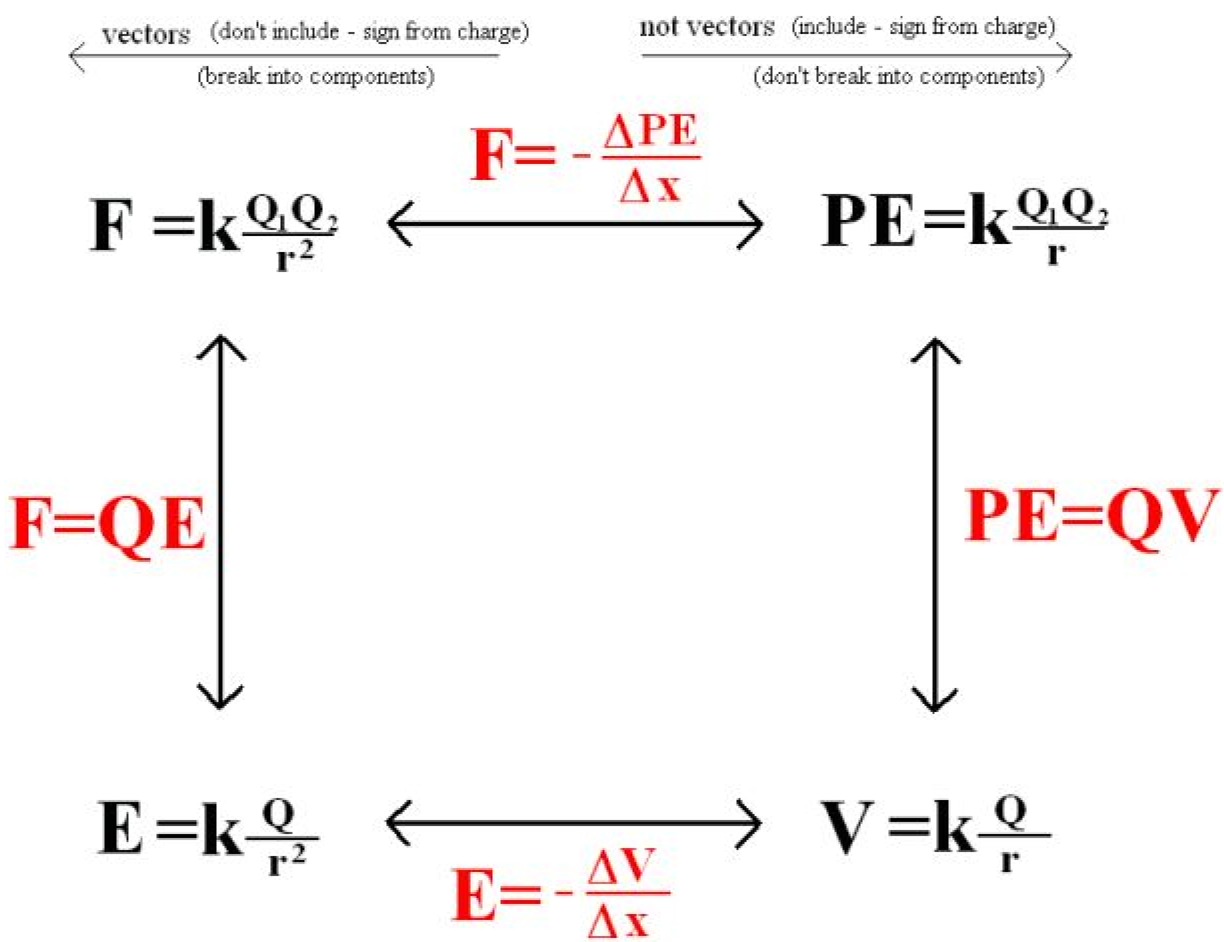
- Interaction between two charges
- Vector and can be attractive or repulsive → opposite charges repulse, like charges attract
- Similar in force to gravity ($F_G = G\frac{mM}{r^2}$)

3.9: Gravitational and Electromagnetic Forces

- Gravity dominates large scale → always add up no “negative mass”
- Electric force dominates human size scale
    - Opposite charges tend to come in equal amounts

3.10: Vector and Scalar Fields in Electricity

- A field is a function of position
- Vector field made of many tiny arrows and shows direction
- Scalar field can be made of contour line and does not show direction
- Note: + and - charges both feel a force toward lower PE, also E point toward lower V



3.11: Electric Charges and Fields

- What is an electric field?

  → At every point in space, there exists a vector quantity of electric field (E), which indicates the force that would act on a positive test charge at that location.

  → This relationship is expressed by the formula:

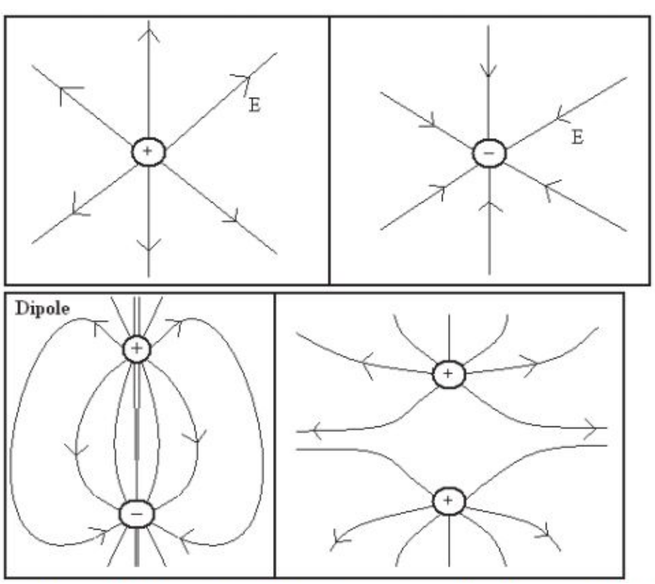
Electric field in N/C or volts/m. $$\vec{E} = \frac{\vec{F}}{q}$$ electric force in Newtons; charge in Coulombs

  → The other formula for E is expressed by:

$$E = k\frac{Q}{r^2}$$ with $$k = \frac{1}{4\pi\varepsilon_0}$$ and k = 9.0 x 10^9 N·m^2/C^2

3.12: Isolines and Electric Fields

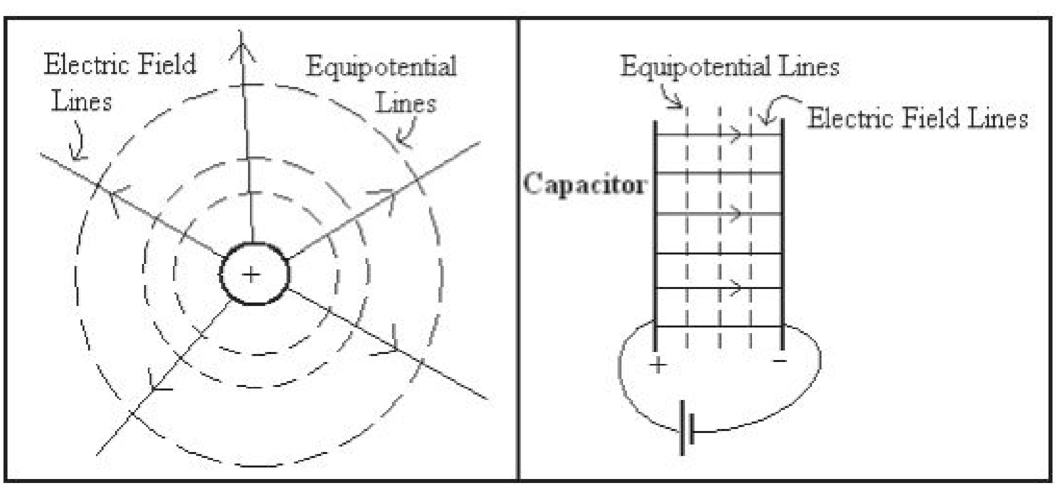
- Isolines are contour lines. → where the electric potential is constant
  - Isolines, also referred to as "equipotentials" are always perpendicular to field lines.
  - These equipotentials are also drawn at equal potential difference spacings
  - One important thing to note about equipotentials is that qualitatively, when equipotentials are closer together, then the magnitude of the field is also stronger. Thus, it follows that when equipotentials are farther apart, then the magnitude of the field is weaker.
- Electric fields are vector fields and are thus represented by arrows



- For a uniform, constant E-field,
  - $\Delta V = -Ed$
  - (d = distance parallel to field line)
    - [On Ap Equation sheet, d=r]
  - We usually see this applied in problems where we have two parallel conducting plates, in between which a constant, uniform E-field is produced.

- For a positive charge under the influence of an E-field:
  - F_E acts in the same direction as the E-field
  - The charge will move in the same direction as the E-field
  - F_E will do positive Work [Since F & d are parallel]
  - ΔU_E (electric potential energy) = negative Work_{FE} = negative change in energy
  - $\Delta V = \Delta U_E/q$ = negative potential difference
    - ΔU_E is - & q is +, so ΔV is negative
  - The positive charge will move from high → low potential
- For a negative charge under the influence of an E-field:
  - F_E acts in the opposite direction as the E-field
    - Because the charge has negative sign.
  - The charge will move in the opposite direction as the E-field
  - F_E will do positive Work [Since F & d are parallel]
  - ΔU_E (electric potential energy) = negative Work_{FE} = negative change in energy
  - $\Delta V = \Delta U_E/q$ = positive potential difference
    - ΔU_E is - & q is -, so ΔV is positive
    - The negative charge will move from low → high potential

- E-fields always point from high potential → low potential
- Equipotential Maps chart out the equipotentials like contour lines in topographic maps.
  - Are always perpendicular to the electric field lines
  - Electric field E is where equipotential lines are closest together
  - No work is done when a charge is moved along an equipotential line
    - $E=-\Delta V/\Delta x$
  - To determine how much potential energy a charge gains moving from equipotential A → B, apply $\Delta U_E = q\Delta V = q(V_B - V_A)$
  - Standard rules for charges on Equipotential Maps written out:
    - + Charges gain U_E when $\Delta V > 0$
      - When moving from low → high potential, + Charges gain U_E
    - + Charges lose U_E when $\Delta V < 0$
      - When moving from high → low potential, + Charges lose U_E
    - - Charges gain U_E when $\Delta V < 0$
      - When moving from high → low potential, - Charges gain U_E
    - - Charges lose U_E when $\Delta V > 0$
      - When moving from low → high potential, - Charges lose U_E

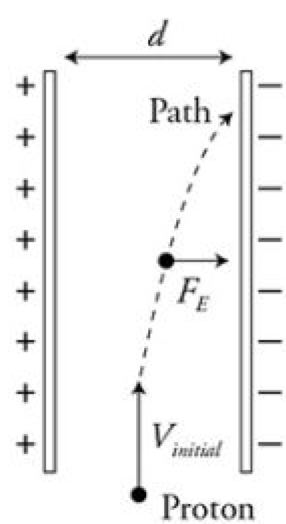


3.13: Conservation of Electric Energy

- The law of conservation of energy states that energy is always conserved and is, therefore, never created or destroyed. All energy, however, can be transferred between different objects or transformed into new forms of energy.
- For example, let us consider a helium nucleus (q=2e) which travels from 7.0 V to 3.0 V
    - $\Delta V = (3.0 \text{ V} - 7.0 \text{ V}) = -4.0 \text{ V}$
    - $\Delta U_E = q\Delta V = 2e(-4.0 \text{ V}) = -8.0 \text{ eV}$ [Lost 8.0 electron-volts of energy]

    - But where did this 8.0 eV of potential energy go?
        - We know from our law of conservation that it could not have simply disappeared, so where is it?
            - It could've been spent on Kinetic Energy, making the particle move faster.
            - Or perhaps, an outside, non-conservative force did -Work on the particle.
- A proton placed between two capacitor plates will accelerate toward the negative plate and away from the positive plate. But, if the proton is shot between the plates, it will experience parabolic trajectory motion just like a football in a gravitational field. In the following diagram, a proton accelerates to the right. The force on the charge is FE = qE = qΔV/d.

And the acceleration of the charge will be $a = \frac{F_E}{m_{proton}}$. Remember that electrons will accelerate in the opposite direction of the electric field!



4: Electric Circuits

4.0: Relevant Equations

Definition of current:	$I = \frac{\Delta Q}{\Delta t}$
Resistance of a wire in terms of its properties:	$R = \rho \frac{L}{A}$
Ohm's law:	$I = \frac{\Delta V}{R}$
Power in a circuit:	$P = I\Delta V$
Equivalent parallel resistance:	$\frac{1}{R_p} = \Sigma_i \frac{1}{R_i} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$
Equivalent series resistance:	$R_s = \Sigma_i R_i = R_1 + R_2 + R_3$
Capacitance of a capacitor based on its properties:	$C = \kappa \varepsilon_0 \frac{A}{d}$
Electric field between the plates of a capacitor:	$E = \frac{Q}{\varepsilon_0 A}$
Charge stored on a capacitor:	$\Delta V = \frac{Q}{C}$
Energy stored in a charged capacitor:	$U_C = \frac{1}{2} Q\Delta V = \frac{1}{2} C(\Delta V)^2$
Equivalent series capacitance:	$\frac{1}{C_s} = \Sigma_i \frac{1}{C_i} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$
Equivalent parallel capacitance:	$C_p = \Sigma_i C_i = C_1 + C_2 + C_3$

4.1: Definition and Conservation of Electric Charge

- In physics, charge conservation is the principle that the total electric charge in an isolated system never changes. The net quantity of electric charge, the amount of positive charge minus the amount of negative charge in the universe, is always conserved.

- Current Equation:
  - $I = \frac{Q}{t}$
  - C/sec = Amperes
  - Defined to be in the direction of positive charge flow (or opposite direction of e)
  - Directed out of the + terminal of a battery and into the - terminal

4.2: Resistivity and Resistance

Resistance = (Resistivity * Length) / Area

$$R = \frac{\rho L}{A}$$

ρ = resistivity
L = length
A = cross sectional area

Resistivity: How strongly a material resists or conducts current.

- Ohm's Law
  - $R = \frac{V}{I}$
  - V is voltage drop across resistor, I is current through resistor, R is resistance
  - V is not necessarily voltage of the battery
  - Ohmic materials have constant resistance (linear slope on V v.s. I graph), while non-ohmic materials have a changing resistance (usually due to temperature changes
  - Slope of V vs. I graph will yield value of resistance.
- Power (in Watts) Functions
  - $P = IV$
  - $P = I^2R$
  - $P = \frac{V^2}{R}$

4.3: Resistance and Capacitance

Capacitors

$C = Q/V$ (C is capacitance, Q is charge on + plate, V is voltage across capacitor)

- Capacitance tells you how well a capacitor can store charge
- Inserting a **Dielectric** between a capacitor always **increases capacitance** by a factor of **k**
- Capacitors store energy as well, which is given by

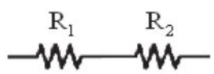
$$E_{capacitor} = \tfrac{1}{2} QV = \tfrac{1}{2} CV^2$$

- For a parallel plate capacitor with plates of area A separated by a distance d, capacitance is,

$$C = \varepsilon_o A/d$$

Resistors in Series

$$R_{eq} = R_1 + R_2$$

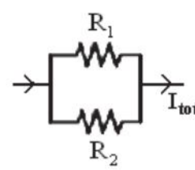


Note: Resistors in Series always have same current

If circuit has only 1 battery, Choose resistors, two at a time, and reduce to a single resistor to determine the current through the battery. Then determine how current breaks up at junctions using these rules

Resistors in Parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$



Note: Resistors in Parallel always have same voltage

If one resistor is 3 times larger than the other, smaller resistor gets 3/4 of the total current	$I_{R_1} = \frac{3}{4} I_{tot}$
If one resistor is 5 times larger than the other, smaller resistor gets 5/6 the total current	$I_{R_1} = \frac{5}{6} I_{tot}$

or, if resistors are not a nice ratio use this formula

$$I_{R_1} = I_{tot} \frac{R_2}{(R_1 + R_2)}$$

Capacitors in Series

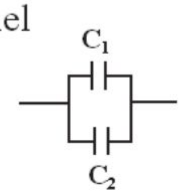
$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

Note: Capacitors in series all have same charge

When you reduce all capacitors to a single C, you can find Q (=CV). Then work backwards to find Q on each capacitor.

Capacitors in Parallel

$$C_{eq} = C_1 + C_2$$



Note: Capacitors in parallel all have same voltage

For capacitors in parallel, if one capacitor has **3** times more capacitance than the other, it gets **3/4** of the total charge.

Or, if not a nice ratio use,

$$Q_1 = Q_{tot} \frac{C_1}{C_1 + C_2}$$

Note: After a short time, current will no longer flow through a C, and any segment of a circuit with a C will have no current.

Capacitance(Parallel Plate):
Units: F(Farad)
Equations:
Q = CV
C = (K ε A)/d = (ε A)/d
E = V/d = Q/(ε A)
U = 0.5QV = 0.5CV^2 = Q^2/(2C)

- U = electric energy
- K = dielectric constant(air = 1)
- ε = constant(8.85 * 10^-12)
- A = area
- d= distance
- Q = charge
- C = capacitance
- V = voltage
- E = electric field

Inserting Dielectric Material(K)(Disconnected From Battery)(Insulator)

- E decreases, V decreases, C increases, ε increases, Q constant, U decreases

Increasing Plate Separation While Connected To Battery

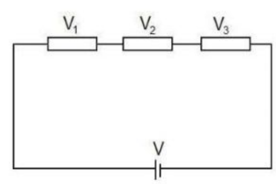
- V constant, C decreases, E decreases, Q decreases (V will never change when connected to battery)

Increasing Plate Separation While Disconnected From Battery

- Q constant, C decreases, V increase, E constant (E field will never change when disconnected from battery)
- Reminder: Capacitors in series store the same charge (because they receive the same current)!

4.4: Kirhhoff's Loop Rule

- The sum of the voltages around a loop in a circuit is zero.
- Kirchoff's Loop rule is due to conservation of energy. Potential difference from a source is positive (it provides potential) and potential difference from a load is negative (since it uses the potential).



$V - V_1 - V_2 - V_3 = 0$

$\Delta V = -IR$ (if you **pass through** resistor in the **same direction as current**)

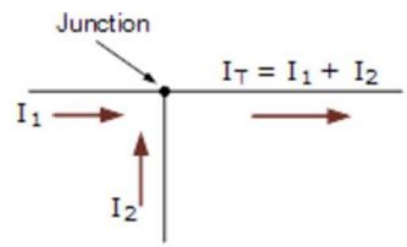
$\Delta V = IR$ (if you **pass through** resistor in the **opp. direction as current**)

$\Delta V = +\varepsilon_{battery}$ (if you **pass through** the battery from – **terminal to + terminal**)

$\Delta V = -\varepsilon_{battery}$ (if you **pass through** the battery from + **terminal to - terminal**)

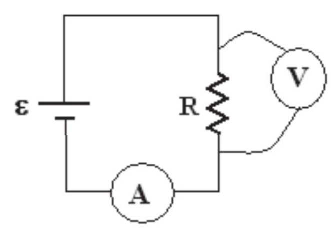
4.5: Kirchhoff's Junction (Node) Rule and the Conservation of Electric Charge

- The current going in a node equals the current coming out a node.
- Kirchoff's node rule is from conservation of charge.



- Voltmeters
  - Measures voltage change across circuit elements (resistor, circuit, etc.)
  - Ideally has infinite resistance so it does not draw current away from the circuit
  - Needs to be hooked up parallel with circuit element
- Ammeters
  - Measures current through a circuit element
  - Ideally has not resistance so that current is left unchanged
  - Needs to be hooked up in series with circuit element
- Terminal Voltage Formula:

$$V = \varepsilon - IR$$



  - Every battery has an internal resistance r which will lower the terminal voltage when current flows
  - A 9V battery will not necessarily have a measured terminal voltage of 9V, unless no current flows
  - The $\mathcal{E}$ of a 9V battery is 9V even when no current flows, but the measured terminal voltage will be less
  - Slope of V v.s. I graph is negative = internal resistance. Y-intercept = emf $\mathcal{E}$
- RC Circuits
  - When capacitor switch is immediately closed, the capacitor acts like a wire allowing current to flow, but the capacitor itself is uncharged
  - When capacitor switch is left on for a long time, the capacitor blocks all current flowing through it, and acts like an open switch
  - When a charged capacitor is disconnected from a battery, it will discharge through a resistor until it's the potential difference across its plates (may be seen as an EMF) reaches zero, momentarily acting as a battery.

5: Magnetism and Electromagnetic Induction

5.0: Relevant Equations

Force on a charged particle moving in a magnetic field:	$\vec{F}_M = q\vec{v} \times \vec{B}$	$\lvert\vec{F}_M\rvert = \lvert q\vec{v}\rvert\lvert\sin\theta\rvert\lvert\vec{B}\rvert$
Force on a current-carrying wire:	$\vec{F}_M = I\vec{\ell} \times \vec{B}$	$\lvert\vec{F}_M\rvert = \lvert I\vec{\ell}\rvert\lvert\sin\theta\rvert\lvert\vec{B}\rvert$
Magnetic field due to a long, straight, current-carrying wire:	$B = \frac{\mu_0}{2\pi}\frac{I}{r}$	
Magnetic flux:	$\Phi_B = \vec{B}\cdot\vec{A}$	$\Phi_B = \lvert\vec{B}\rvert\cos\theta\lvert\vec{A}\rvert$
Induced emf:	$\varepsilon = -N\frac{\Delta\Phi_B}{\Delta t}$	
Induced emf for a wire moving through a magnetic field:	$\varepsilon = B\ell v$	

5.1: Magnetic Systems

- Like poles on different magnets repel each other; unlike poles attract.
- Surrounding a magnet is a three-dimensional magnetic field. The direction of the magnetic field at any point in space is the direction indicated by the north pole of a small compass needle placed at that point.

5.2: Magnetic Permeability and Magnetic Dipole Moment

- Matter and space have a magnetic permeability → how much they let the field through
- Matter has a magnetic dipole moment
- Magnetism is caused by alignment of magnetic moments

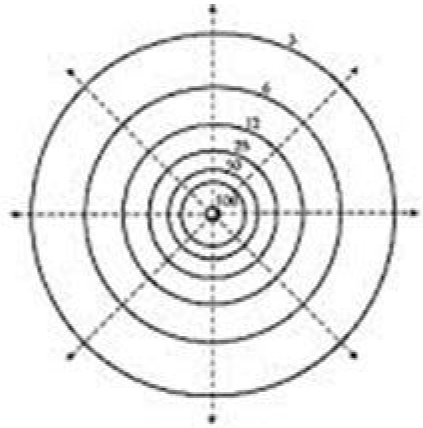
5.3: Vector and Scalar Fields in Magnetism

- A field is a function of position
- Vector fields are represented by little arrows (into the page is ⊗ out is ⊙)
- The vector field is a sum of all the vector fields that are related, vector addition
- Scalar field is a field of numbers, represented by contour lines
- The scalar field is a sum of all scalar fields that are related, scalar addition

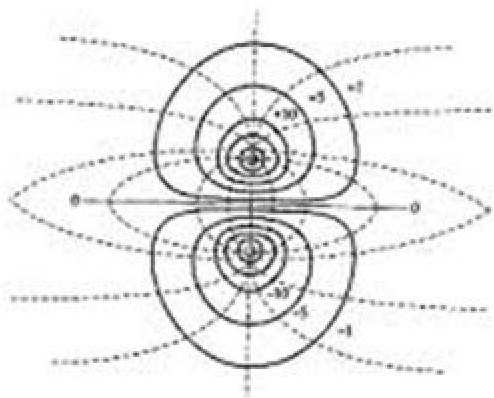
5.4: Monopole and Dipole Fields

- Monopole fields: ex. Gravitational field w/ spherical mass & electric field due to a single pt. Charge.

- Dipole fields: ex. Electric & magnetic dipoles, vector addition of fields including identifying each source, locations, and signs of sources.



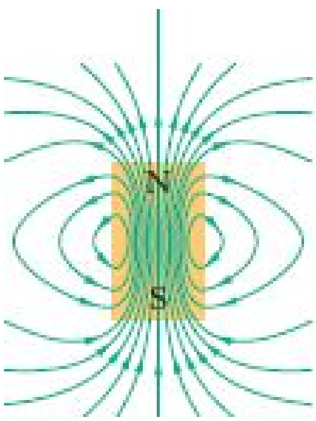
Monopole

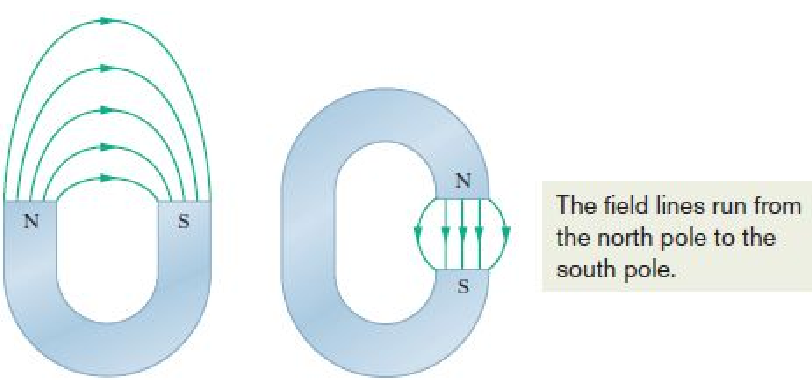


Dipole

5.5: Magnetic Fields and Forces

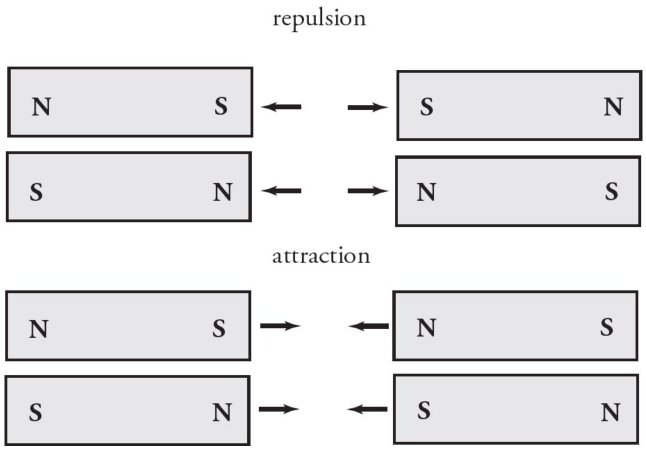
Magnetic field lines, similar to dipole fields line in electrostatics.



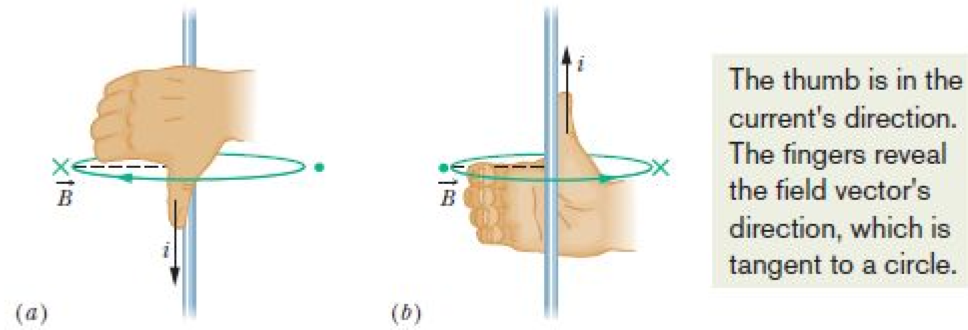


Convention for magnetic field symbol x = magnetic field into the page , • = magnetic field out of the page.

As with electric charges, like magnetic poles repel each other, while the opposite magnetic poles attract each other.



A right hand rule gives the direction of magnetic field due to a current in the wire



Magnetic field due to a current in a long (infinite) straight wire at a distance R is

$$B = \frac{\mu_0 i}{2\pi R}$$

$\mu_0 = 4\pi \times 10^{-7}\ H/m$

5.6: Magnetic Forces

For charge that moves in magnetic field will get a magnetic force

$$F = q\,v \times B \text{ (in vector form)}$$

$$F = qvB \sin\theta \text{ (magnitude of the force)}$$

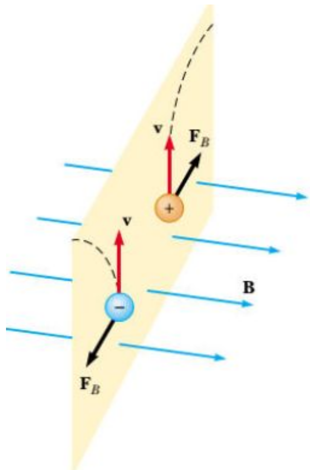
With q = charge (C) , v = velocity (m/s), and B = magnetic field (T)
The magnetic force always perpendicular to velocity and magnetic field

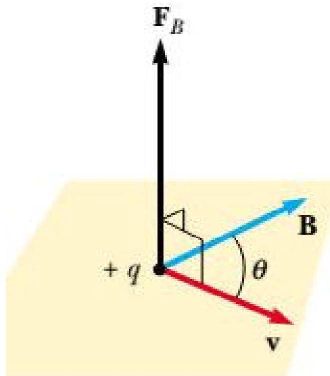
$$F \perp v,\ B$$

As a result of this, magnetic force CANNOT DO WORK!

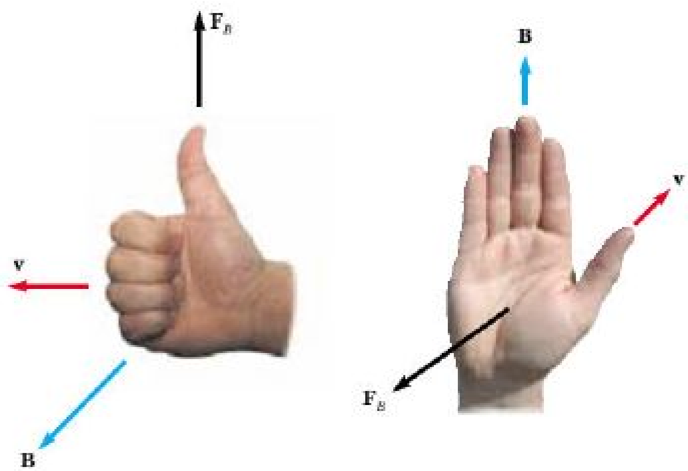
Note:

$$v = \frac{E}{B}$$



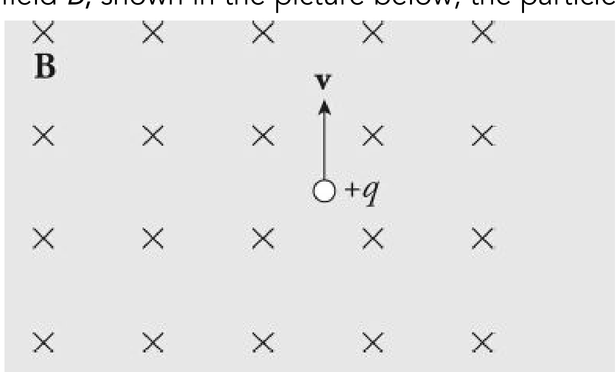


Direction of force given by right hand rule:



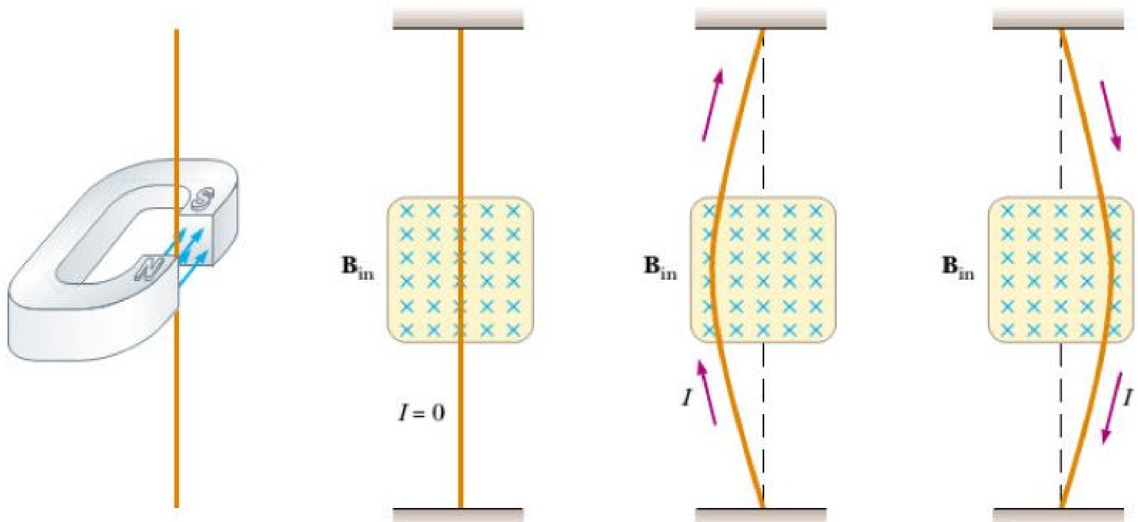
For negative charge the magnetic force will be in the opposite direction.

For a charged particle with charge *q* and mass *m,* moving with velocity *v* in uniform magnetic field *B*, shown in the picture below, the particle will move in a circle.

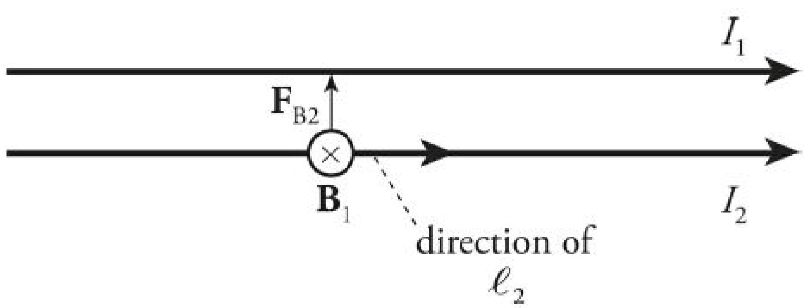


The radius of the circle is $r = \frac{mv}{qB}$

For a wire that has a current flowing through in a magnetic field, the wire will get magnetic force. Magnitude of the force per unit length is $F = ILB\sin\theta$, with L is the length of the wire (m), I = current (A), B = magnetic field (Tesla). For the direction of the force you could use the right hand rule by changing the velocity direction with the direction of current.



Two wires with current I_1 and I_2 flowing in the same direction will be attracting each other. When the current is flowing in the opposite direction the wires will be repelling each other.



$F_{B2} = I_2 l_2 B_1 = I_2 l_2 \frac{\mu_0}{2\pi}\frac{I_1}{r} \Rightarrow \frac{F_{B2}}{l_2} = \frac{\mu_0}{2\pi}\frac{I_1 I_2}{r}$

Using newton third law, wire 1 will feel the same force, but in the opposite direction.

5.7: Forces Review

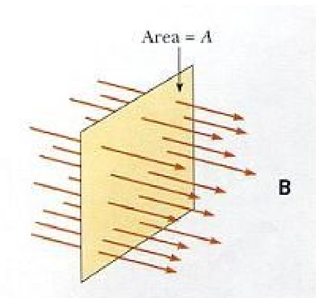
- Forces are described by vectors and are detected by their influence on the motion of an object.
- An object cannot exert a force on itself, the force on an object is always due to an interaction with another object.

- The acceleration of an object is always in the direction of the net force exerted on the object, but the velocity may not necessarily also be in the same direction.

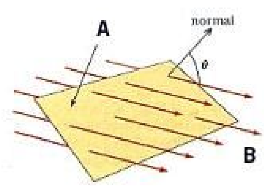
5.8: Magnetic Flux

- Magnetic flux is a measure of the amount of magnetic field passing through a surface. It's directly related to the number of fieldlines that pass through a surface.

Formula for magnetic flux:



$\Phi = BA$



$\Phi = BA\cos\theta$

Induced voltage ε

$\varepsilon = -\Delta\Phi_M/\Delta t$ (magnetic flux $\Phi_M = BA\cos\theta$ A is the area of the loop of wire)

$\varepsilon = \Delta(BA\cos\theta)/\Delta t$

- You will induce a voltage in a loop of wire if you change **B, A, or θ**

For a piece of wire or a conducting bar of length L the induced voltage will be

$\varepsilon = LvB$ (remember there is voltage on Las Vegas Boulevard)

$$\phi⍰ = BA\cos\theta$$

- ϕ⍰: magnetic flux
- A – area of surface; there is more flux when the field passes through a larger surface
- θ – angle between field line and surface; there is more flux when the field lines pass straight through the surface rather than passing through at an angle.
- *units of magnetic flux – Webers, Wb
- *Magnetic field is also called magnetic flux density

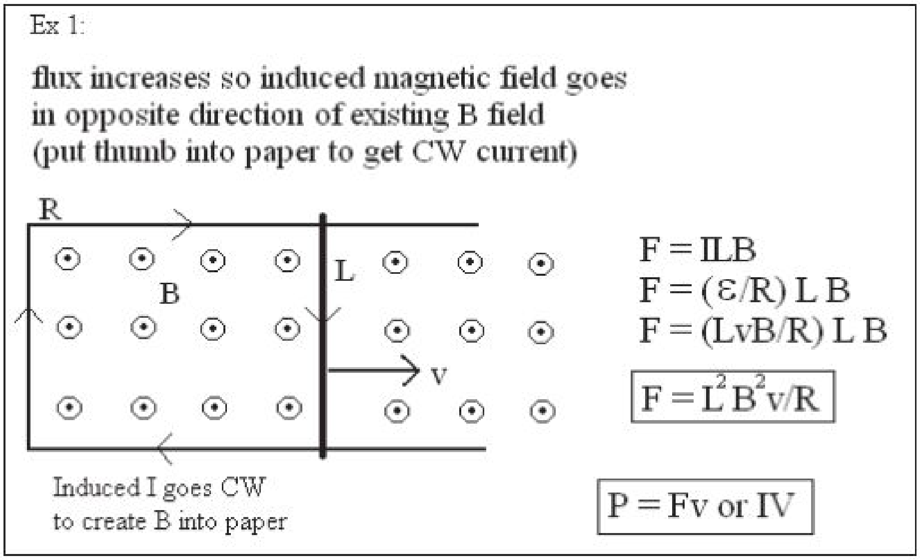
Lenz's Law:

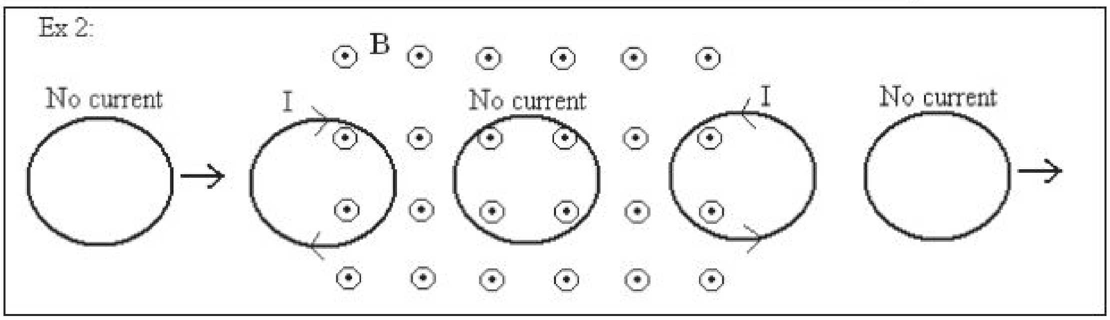
- States that the induced current will be in the direction that produces an induced magnetic field that opposes the original change in flux.

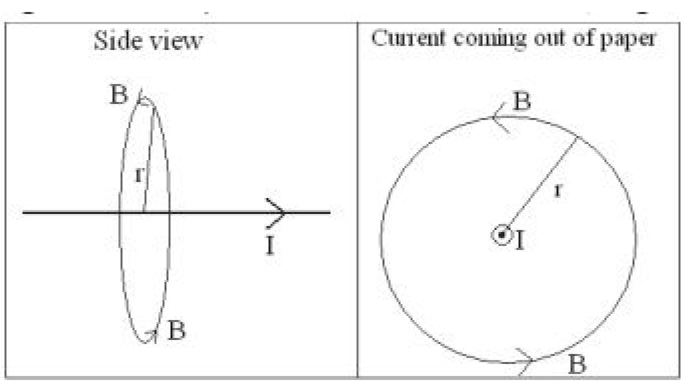
- If flux increases, induced current creates a magnetic field B in opposite direction of existing B
- If flux decreases, induced current creates a magnetic field B in same direction of existing B

- To visualize this, imagine a region of constant magnetic field B pointing out of page. On the left of the field, imagine an iron coil such that it is not in the area of influence of the field.
  - Imagine t_1 as the time when the coil moves right but is still outside the B-field. At this time, the coil is still exposed to 0 Magnetic Field lines so the change in magnetic flux ($\Delta\phi$) = 0, and no current and magnetic field is induced.
  - Picture t_2 as the time when the coil is moving right but partially outside the B-field and partially inside the field. At this time, the number of magnetic field lines the coil is exposed to is increasing so the change in magnetic flux ($\Delta\phi$) > 0.
    - To oppose this increase in flux, a current will be induced inside the coil to "*counter*" the original B-field pointing out of the page which is contributing to the increase in flux.
    - The "counter" to a B-field pointing out of the page would be one into the page.
    - Doing our right hand rule, we determine that in order for the coil to produce a B-field into the page within the area of the coil, the direction of the induced current would have to be clockwise.
  - Consider t_3 as the time when the coil is fully inside of the B-field. At this time, similarly to t_1, the coil is still exposed to a constant number of Magnetic Field lines so the change in magnetic flux ($\Delta\phi$) = 0, and no current and magnetic field is induced.
  - Now think of t_4 as the time when the coil is moving right leaving the B-field but partially in and out of it. At this time, the number of magnetic field lines the coil is exposed to is decreasing so the change in magnetic flux ($\Delta\phi$) < 0.
    - To oppose this decrease in flux, a current will be induced inside the coil to "*augment*" the original B-field pointing out of the page from which there is a decrease in flux.
    - The "augment" to a B-field pointing out of the page would be one also out of the page.
    - Doing our right hand rule, we determine that in order for the coil to produce a B-field out of the page within the area of the coil, the direction of the induced current would have to be counter-clockwise.

- Think of time t_5 as the same as in t_1, where the coil is out of the B-field moving to the right. At this time, the coil is still exposed to 0 Magnetic Field lines so the change in magnetic flux ($\Delta\phi$) = 0, and no current and magnetic field is induced.







- Note: Wires with same I in same direction will attract, opposite direction will repel

FRQ Tips

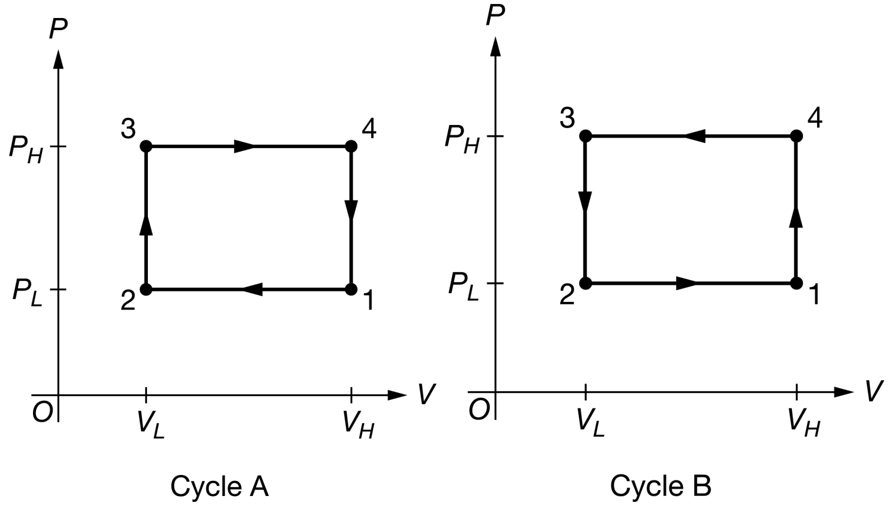
Experimental Design Tips

Design a Lab to . . .	Useful Equations
Find or investigate the density of an object.	$\rho = \frac{m}{V}$, $P = P_0 + \rho gh$, $F_b = \rho Vg$
Determine if a gas displays ideal gas properties.	$PV = nRT$
Analyze data about thermal conductivity.	$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$
Analyze the work done by a gas.	$W = -P\Delta W$
Qualitatively investigate the charge of an object and the induced charge on objects.	$\lvert\vec{F}_E\rvert = \frac{1}{4\pi\varepsilon_0}\frac{\lvert qq\rvert}{r^2}$
The effect of the geometry of an object on its resistance.	$R = \frac{\rho l}{A}$
Analyze the properties of circuits including those with capacitors.	$P = I\Delta V$, $I = \frac{\Delta V}{R}$, $R_S = \Sigma_i R_i$, $\frac{1}{R_p} = \Sigma_i \frac{1}{R_i}$ $C_p = \Sigma_i C_i$, $\frac{1}{C_S} = \Sigma_i \frac{1}{C_i}$
Determine the effect of geometry changes on capacitance.	$C = \kappa\varepsilon_0\frac{A}{d}$, $\Delta V = \frac{Q}{C}$
Investigate the force on moving charges caused by a current carrying wire.	$B = \frac{\mu_0 I}{2\pi r}$, $F_M = qvB\sin\theta$

Paragraph Length Responses Tips

- Before you write anything, remember: Less is better than more. This is not an English exam. The humans grading the free response are physics people. They do not want fluff. They are looking for specific information that tells them you understand the physics of the situation.
- Here is an acronym that will help: CLEVeR.
    - 1. CL—Make your CLAIM.
    - 2. EV—Give your EVIDENCE.
    - 3. R—Explain your REASONING

- Example Question and Response:

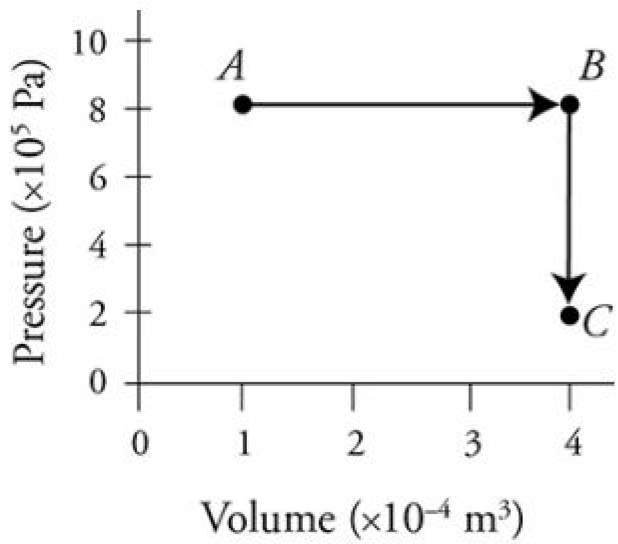


Sample A of a gas is taken through cycle A between states 1, 2, 3, 4, and 1, as shown in the graph of pressure P as a function of volume V for cycle A. Identical sample B of the gas is taken through cycle B between states 1, 4, 3, 2, and 1, as shown in the graph for cycle B.
a) Describe the difference, if any, in the net work done on each sample of gas as it is taken through the cycles shown above. Explain how the location of the states on the graphs and the direction of the processes in each cycle can be used to arrive at your answer.
    - Correct Claim: More work is done on sample B than on sample A .
    - Evidence: The areas of the cycles are the same and the direction of the cycles are opposite.
    - Reasoning: In cycle A , more work is done by the gas in process 3 to 4 than is done on the gas in process 1 to 2, because there is more area under the line for process 3 to 4 than there is for process 1 to 2. In cycle B , more work is done on the gas in process 3 to 4 than is done by the gas in process 1 to 2, because there is the same difference in areas under the lines.
    - Example Response: More work is done on sample B than on A , because the net work in cycle A is negative and the net work in cycle B is positive. In cycle A , more work is done by the gas in process 3 to 4 than is done on the gas in process 1 to 2. In cycle B , more work is done on the gas in process 3 to 4 than is done by the gas in process 1 to 2.

QQT Tips

- This is a qualitative reasoning question asking you to use words to make your argument. Part (b) asks for an algebraic derivation. This is a quantitative reasoning question asking you to use math to make your argument. Quantitative reasoning would also include finding a number answer similar to if you had been asked to calculate the wavelength of the emitted photon. The QQT question will ask you to consider a situation and explain it first qualitatively (with words) and then quantitatively (with equations and numbers).

You probably have been solving lots of number problems in your AP Physics 2 class and use your calculator a lot. As a consequence, you may be more comfortable with number problems. If this is the case, play to your strengths and solve the number part of the problem first, and then answer the conceptual part. Here is an example below:



- Two moles of gas are taken from its original state at point A through point B to a final state at point C as shown in the graph. A student makes this statement: "The net heat added or subtracted from the gas is zero because the final temperature of the gas is the same temperature as its starting temperature."
    - (a) Do you agree or disagree with the student's statement? Explain your reasoning with words.
    - (b) Justify your argument with a calculation.
- Solving part (b) with equations: PAVA = PCPC = nRT, since the PV value at points A and C are the same, the temperature change in the process is equal to zero. ΔU = nRΔT = 0, since the change in temperature during the process is zero, the change in internal energy is also zero. WA→B→C = –PΔV = –(800,000 Pa)(0.0004 m3 – 0.0001 m3) = –240 J, there is no work done moving from point B to C as there is no change in volume. ΔU = 0 = Q + W, therefore Q = –W = –(240 J) = 240 J..
- Now that you have the math worked out, put it in words to answer (a). Remember to be CLEVeR with your response!
    - I agree the temperatures at A and C are the same because the pressure times volume is the same at both locations. I disagree that the heat is zero. Since the temperature does not change, the change in the internal energy of the gas is zero. There is negative work done by the gas during its expansion. Therefore, heat must be added to the system.
- Choose to approach the QQT question with numbers first and words second, or words first and numbers second. It doesn't matter. The key is to play to your strengths so that you earn as many points as you can.

Final Thoughts

You got this guys! I know that if y'all took this cursed class, you must be some pretty smart Physics Folks. So be proud, don't be nervous, and cap that 5!

Neko knows you can do it too! OWO

- Mirradow#5563