UIL Physics Notes

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notes

1 Motion

Anything related to moving things excluding those primarily concerned with force.

1.1 Kinematic Formulas

There are four kinematic formulas (only use when acceleration is constant). In the following formulas, v_0 = initial velocity, v = final velocity, a = acceleration, t = time, and Δx = displacement. Velocity is given in $\frac{m}{s}$, acceleration is given in $\frac{m}{s^2}$, time is given in s, and displacement is given in m.

1. $v = v_0 + at$
   - Change in velocity is equal to acceleration times time.
2. $\Delta x = \left(\frac{v + v_0}{2}\right) t$
   - Displacement equals the average velocity times time using final velocity.
3. $\Delta x = v_0 t + \frac{1}{2}at^2$
   - Rearranged into $\Delta x = t\left(v_0 + \frac{1}{2}at\right)$ and using equation 1, this equation is another version of displacement equals average velocity times time without final velocity.
4. $v^2 = v_0^2 + 2a\Delta x$
   - Use when no time is given.

2 Force

Anything related to forces.

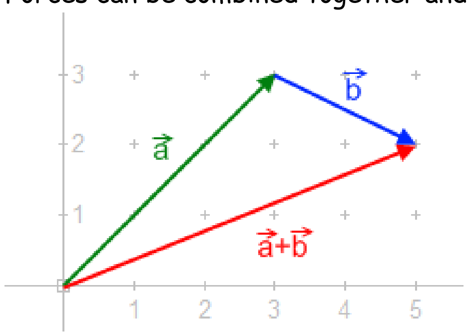
2.1 Basic

The most basic formula is

$$F_{net} = ma$$

where F = force (a vector with direction), m = mass, and a = acceleration. The m is in kg, a is in $\frac{m}{s^2}$, and F is in $\frac{m \cdot kg}{s^2}$, or N.

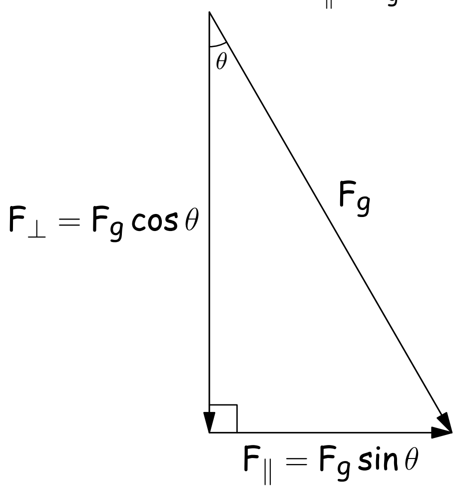
Forces can be combined together and decomposed using the head to tail method as shown below.



In the event that the forces form a right triangle (usually vertical + horizontal forces), it becomes trivial to calculate and decompose forces given the angle measures.

2.2 Angles and Stuff

When an object is on an inclined plane, rotate the free body diagram such that the surface the object is on is parallel to to the ground, preserving forces. Let the angle the plane makes with the ground be θ and the force of gravity be F_g. The downward force on the rotated free body diagram is $F_\perp = F_g \cos\theta$. The horizontal force is $F_\| = F_g \sin\theta$.



2.3 Friction

There are two types of friction (static and kinetic). Static friction keeps the box from moving when it is at rest. Kinetic friction acts when the object is already moving. The coefficient of friction of an object is described by μ. The static friction is μ_s, and the kinetic friction is represented by μ_k. Normal force, or F_n, is the force that the surface the object is resting on is exerting on the object (if its flat, its opposite gravity, but if its not, see section 2.2). The force of static friction is

$$F_s \le \mu_s F_n$$

As more force is applied to the object, the more force static friction will push back. Once the force applied exceeds the static friction, the object will start moving. The force of kinetic friction is

$$F_k = \mu_k F_n$$

Most of the time, $\mu_k < \mu_s$.

3 Uniform Circular Motion

3.1 Basics

Measure angular displacement as $\Delta\theta = \theta_f - \theta_i$ in radians. Angular velocity (analagous to velocity) is $\omega = \frac{\Delta\theta}{\Delta t}$ in radians per second. Angular acceleration (analagous to acceleration) is $\alpha = \frac{\Delta\omega}{\Delta t}$ in radians per second squared. CCW is positive, and CW is negative.

3.2 Relation to normal stuff

Distance/arc length (S) is $S = |\Delta\theta| r$, where r is the radius. The speed is $V = \frac{S}{\Delta t} = \frac{|\Delta\theta| r}{\Delta t} = |\omega| r$. The acceleration is $a_{tan} = |\alpha| r$

3.3 Period vs. Frequency

The period (T) in seconds is how long it takes to complete a cycle (around the circle). The frequency (f) is $f = \frac{1}{T}$ in s^{-1}, or Hertz (Hz). The period can be found by $t = \frac{d}{r}$, or $T = \frac{2\pi}{\omega}$.

3.4 Centripetal Acceleration

When something is traveling in a circle, it is experiencing acceleration, as the direction of the velocity is changing. The centripetal acceleration is $a_c = \frac{v^2}{r}$, where v is speed in m/s. (Derivation comes from creating a second circle where velocity vectors are radii and acceleration is tangent). It can also be expressed as $a_c = r\omega^2$. The centripetal acceleration always goes towards the center.

3.5 Gravity

Things like being close to other things. $F_g = G\frac{m_1 m_2}{r^2}$ where G is gravitational constant (very small), m_1 and m_2 are the masses, and r is radius. $G \approx 6.67 \times 10^{-11} N \times (m/kg)^2$. The gravitational field force is $g = G\frac{m}{r^2}$ (in m/s^2).

4 Work

4.1 Basics

Work is calculated as $W = Fd\cos\theta$, where W is work in joules, F is force, d is displacement, and θ is the angle at which the force is applied in relation to the direction if displacement (area under graph of force to displacement). Another way to express work is $W = \Delta K$, where K is kinetic energy.

4.2 Kinetic Energy

Kinetic energy is energy from motion. $K = \frac{1}{2}mv^2$. This can be derived from $W = mad = K_f - K_i$, and because $v^2 = v_0^2 + 2ad$, then $d = \frac{v^2 - v_0^2}{2a}$. This means $ma\frac{v^2 - v_0^2}{2a} = K_f - K_i$, or $\frac{1}{2}mv^2 - \frac{1}{2}mv_0^2 = K_f - K_i$.

4.3 Conservative Forces

The work done by a conservative force to move an object from point A to point B is same no matter what path it takes (usually mechanical, such as gravity or springs). Non-conservative forces, such as friction and air resistance, depend on the path taken. Conservative forces have potential energies, such as gravitational potential energy or spring potential energy. Gravitational potential energy is $\Delta U_g = mg\Delta y$.

4.4 Law of Conservation of Energy

Total energy of an isolated system is constant. Energy is neither created or destroyed. It can only be transformed or transferred. For mechanical energy, $K_i + U_i = K_f + U_f$ and $\Delta K + \Delta U = 0$. To factor in non conservative forces, $K_i + U_i + W_{NC} = K_f + U_f$ and $\Delta K + \Delta U = W_{NC}$.

4.5 Power

Power is work/time, joules/seconds, or watts (W). $P = \frac{W}{\Delta t}$, which results in $P = Fv\cos\theta$.

5 Linear Momentum and Collisions

5.1 Basics

Momentum, represented as P, is $P = mv$. Since $F = ma$, which can also be written as $F = \dfrac{\Delta(mv)}{\Delta t}$, $F = \dfrac{\Delta P}{\Delta t}$. Impulse is $J = \Delta P = F\Delta t$. Impulse is also area under a force vs time graph.

5.2 Elastic vs Inelastic Collisions

For elastic collisions, total kinetic energy is constant ($K_{1i} + K_{2i} = K_{1f} + K_{2f}$). Inelastic collisions tend to have more kinetic energy before, generally converted to heat, so $K_{1i} + K_{2i} < K_{1f} + K_{2f}$. Totally inelastic collisions are when two objects stick to each other. ($K = \frac{1}{2}mv^2$).

5.3 Conservation of Momentum

Momentum in a closed system is conserved. $P_i = P_f$. Additionally, in an elastic system (momentum and kinetic energy are conserved), $v_{1i} - v_{2i} = v_{2f} - v_{1f}$.

5.4 Center of Mass

The center of mass is a point where you can pretend the entire object exists at that point. For example, if you apply a force at the center of mass, you can treat the mass as a point. If the force is not applied at the center of mass, the object will rotate around its center of mass. The center of mass is $x_{CM} = \dfrac{m_1x_1 + m_2x_2 + \dots}{m_1 + m_2 + \dots}$. Additionally, the velocity of a closed system's center of mass does not change.

6 Torque and Angular Momentum

6.1 Basics

Rotational motion variables correspond to linear motion variables.

$\Delta\theta = \theta_f - \theta_i$, $\Delta x = x_f - x_i$.

$\omega = \dfrac{\Delta\theta}{\Delta t}$, $v = \dfrac{\Delta x}{\Delta t}$.

$\alpha = \dfrac{\Delta\omega}{\Delta t}$, $a = \dfrac{\Delta v}{\Delta t}$.

6.2 Rotational Kinematics

These are the same as linear kinematics with constant acceleration, just replaced with rotational motion variables.

1. $\omega = \omega_0 + \alpha t$
2. $\Delta\theta = \left(\dfrac{\omega + \omega_0}{2}\right)t$
3. $\Delta\theta = \omega_0 t + \dfrac{1}{2}\alpha t^2$
4. $\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$

6.3 Torque

Torque (τ) is $\tau = F_{\perp}d = Fd\sin\theta$ with units as $N \cdot m$. The distance (d) from the pivot point is called moment arm distance. (CCW is positive, CW is negative). When an object is at rest, net torque ($\Sigma\tau$) is 0.

6.4 Rotational Inertia and Rotational 2nd Law

The rotational analogue of 2nd law is $\tau = I\alpha$ where α is rotational acceleration (acceleration), τ is torque (force), I is moment of inertia/rotational intertia (mass). $I = mr^2$ (derive by convert a_{tan} to α).

6.5 Rotational Kinetic Energy

Just as kinetic energy $K = \frac{1}{2}mv^2$, for rotational energy is $K_{rot} = \frac{1}{2}I\omega^2$. When an object is rolling without slipping, $v = r\omega$.

6.6 Angular Momentum

Angular momentum is $L = I\omega$, and for angular impulse, $\Delta L = \tau\Delta t$. Additionally, angular momentum is conserved ($L_i = L_f$ or $\Delta L = 0$).

6.7 Gravitational Potential Energy

Recall that $F_g = G\frac{m_1m_2}{r^2}$. Gravitational potential energy is just $U_G = G\frac{m_1m_2}{r}$.

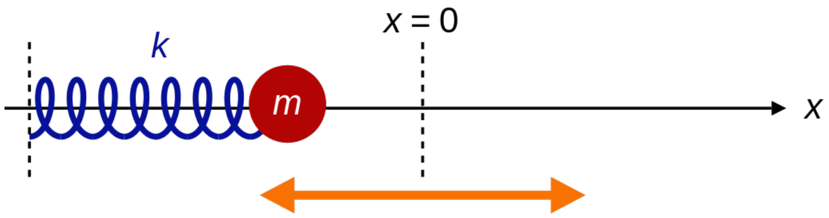
7 Harmonic Motion

7.1 Amplitude, Period, Frequency

Amplitude (A) is the maximum magnitude of displacement (distance) from the equilibrium position. Period (T) is the amount of time to "reset" to same position and velocity. Frequency (f) is the inverse of the period ($f = \frac{1}{T}$).

7.2 Simple Harmonic Oscillators

Harmonic motion is like a spring:



In simple harmonic oscillators that go through simple harmonic motion (SHM), the restoring force is proportional to displacement. Note that gravity does not affect SHOs much, as they just lower the equilibrium point.

7.3 Hooke's Law

The spring force can be calculated as $F_s = -kx$, where k is the spring constant in kg/s^2 or N/m, x is the displacement (vector), and F_s is the force.

7.4 Graphing SHOs

The horizontal position of the SHO can be represented as $x(t) = A\cos\left(\frac{2\pi}{T}t\right)$ (Amplitude is A and period is T). If the mass starts at negative displacement extreme, use $-\cos$. If the mass starts at equilibrium and goes up, use sin. If the mass starts at equilibrium and goes down, use $-\sin$.

7.5 Period Properties

Changing the amplitude does not affect period, as the longer distance and increased force cancel each other out. However, it is dependent on the mass (m) and the spring constant (k).

$$T = 2\pi\sqrt{\frac{m}{k}}$$

As the mass increases, the period obviously increases, and the more force the spring exerts, the less the period is.

7.6 Energy In SHM

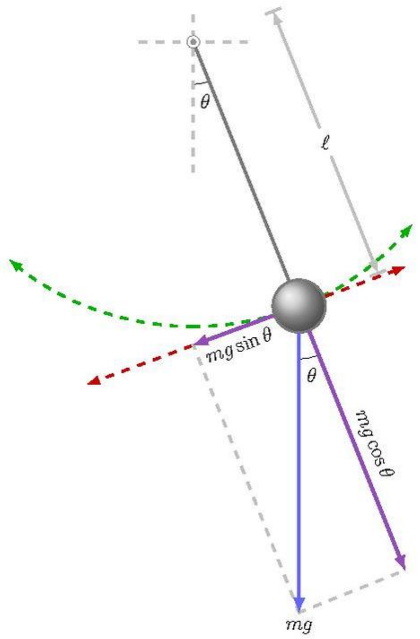
Elastic potential energy gets converted into kinetic energy and back again. The elastic potential energy is highest at the amplitude position (farthest from equilibrium). The kinetic energy is highest at the equilibrium position. In a closed system such as this one, the total energy ($U_s + K$) would be constant. U_s, or the elastic potential energy, is $U_s = \frac{1}{2}kx^2$ (Derive from force displacement graph). The kinetic energy is $K = \frac{1}{2}mv^2$.

7.7 Approximate Pendulums

Another formula is one that calculates the approximate period (time to swing across and back again) of a pendulum given its length. The equation is

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where T = period in seconds, L is the length in meters, and g is the acceleration of gravity in $\frac{m}{s^2}$. This is analogous to the SHM period formula, as the mass and the length are both inertia, and the spring constant and gravitational constant are both force.



From this diagram, we can see that the the horizontal force on the pendulum is $\mathrm{mg}\sin\theta$. When the value of θ (in radians) is small (less than approximately 15 degrees, or about 0.25 radians), $\sin\theta \approx \theta$.

8 Waves

A wave is a disturbance propagating through space that usually transfers energy. Transverse = wave in a rope, longitudinal wave/compression wave = sound through air. A pulse is one disturbance, and a periodic wave is one that repeats.

8.1 Periodic Waves

Amplitude (A) = the distance from resting point to the crest/trough.
Period (T) = Seconds per cycle
Frequency ($f = \frac{1}{T}$) = Cycles per second (Hertz / hz)
Wavelength (λ) = distance wave travelled for one period (crest to crest)
Velocity ($v = \frac{d}{t} = \frac{\lambda}{T} = \lambda f$) = The speed at which the wave travels.
Velocity also equals $v = \sqrt{\frac{T}{m/L}}$.
Expansion = max spacing for longitudinal wave
Compression = min spacing for longitudinal wave

8.2 Wave Interference

When two or more waves overlap in same region. For two waves of height y_1 and y_2, $y_t = y_1 + y_2$ (Superposition principle). Constructive interference is when overlapping waves produce a wave with larger amplitude. Destructive interference is when overlapping waves produce wave with less amplitude.

8.3 Standing Waves on Strings

An example of a standing wave is nailing both ends down (violin string). The not moving points are called nodes. Antinodes are the place with most motion. When a wave hits a node, it gets flipped upside down. The fundamental wave (first harmonic) is the one which the wave stretches from one node to the other. The second harmonic has the wavelength halved, and so on.

The nth harmonic has a wavelength of $\lambda_n = \frac{2L}{n}$.
The nth harmonic has a frequency of $f_n = f_0 n$

8.4 Sound

Sound transports kinetic energy through a longitudinal wave with air as the medium. The louder the sound, the larger the amplitude. The lower the period (higher the frequency), the higher the pitch is. The wavelength is different than period or frequency ($\lambda = \frac{v}{f}$). The speed of sound at $20°$C non humid air is 343 m/s. (open tubes have antinodes at both ends while closed tubes have a node at one end and an antinode at the other end) A pressure node is equal to the antinode of the displacement node (and vice versa).

8.5 Beat Frequency and Wave Interference

Two waves with same period/frequencies will always be either constructive or destructive and stay that way. Two waves with different periods/frequencies will result in beats (constructive $\Rightarrow$ destructive $\Rightarrow$ constructive $\Rightarrow$ etc). The equation for beat frequency is $f_B = |f_1 - f_2|$.

8.6 Doppler effect

Effect from waves emmited from moving sources. When an object is moving towards the observer, the wavelength is longer (by the length the emitter moved in a period of the normal wave).

9 Charged Things (Electrostatics)

Electrons and protons and stuff.

9.1 Charge Basics

If an object loses electrons, then it becomes positively charged. If an object gains electrons, it becomes negatively charged (positive charges don't move in atoms). Unit or charge = coulomb.

9.2 Methods of Charging

1. By Friction (ex. rubbing hair + balloon results in hair +, balloon -)
2. By Induction (positively charged object attracts electrons from two touching objects, remove connection between two touching objects, one is +, one is -) (polarizing).
3. By Touch (when two differently charged objects touch, the charge gets evenly distributed between them.

9.3 Conservation of Charges

You cannot destroy charge or create charge; you can only transfer or redistribute charges from one object to another. An object with +4c and -1c touch, both have +1.5c.

9.4 Forces between charges

Coulomb's Law: $F_e = \frac{kQ_1Q_2}{d^2}$ Newtons where Q_1 and Q_2 are charges in coulombs ("c"). One coulomb is a lot of charge, as one electron has 1.6×10^{-19} coulombs. k is approximately $9 \times 10^9 \text{Nm}^2/\text{c}^2$, and d is in meters. Like charges repel, and different sign charges attract with the force provided by Coulomb's Law (+ and + repel, - and - repel, - and + attract). Example 1: two charges with charge +4c and -2c. Since they are different sign charges, they attract. If they are 20cm apart, then the force is $F_e = \frac{9 \times 10^9(4)(2)}{0.2^2}$ Newtons. With multiple charges, calculate the force on each and combine them.

9.5 Electric Fields

Fields are created by charges, and $E = \frac{kQ}{d^2}$ where Q is the charge in coulombs and d is the distance in meters from the charge. E is a vector of force at some point A. The direction of the force points away from the charge if they are positive or points towards the charge if they are negative. Example 1: A charge with +1c is 3 meters to the left of a charge with -2c. What is the force at point A 1.5 meters from each particle? The total E is the sum of all E_i for each particle. ($E = E_1 + E_2$ or $E = \frac{k(1)}{1.5^2} + \frac{k(2)}{1.5^2}$).

9.6 Connection between Coulomb's Law and electric field

$E = \frac{F_e}{q}$ where q is the charge of a testing charge.

9.7 Electric Potential (Scalar)

This is not directional. $V = \frac{kQ}{d}$. V is electric potential at some point (unit = volt). When calculating potential, leave the positive + negative sign. Total V is sum of all V_i.

9.8 Interactive Energy between charges (Scalar)

$U = \frac{kQ_1Q_2}{d}$. U is potential energy in joules. With this calculation, leave the positive and negative signs. Total potential energy is the sum of all U between charges.

9.9 Uniform Electric Field

A uniform electric field is same in a area (line of positives parallel to a line of negatives). Any charge (with same charge) between the parallel lines has same force exerted. Voltage is potential differences (electric potential or Δv). $\Delta v = E \times d$. E (+ to -) goes in the direction of which the potential decreases. In addition, $F_e = qE$, so given the Δv and distance between plates, you can calculate the electric field and the force on charges.

9.10 Electrostatic Equilibrium

After the charges redistribute in a conductor due to an external charged particle. When there is force from an electric field, the electrons will continue to redistribute. After electrostatic equilibrium has been reached, then there will be no more electric field present inside the conductor. (Inside a shield, there is a field. Outside a shield, there is a field. However, inside the field, there is no field). The calculations inside and outside the field are unaffected.

10 Circuits

10.1 Units

Voltage (V) is electric potential energy (joules) per unit charge (coulomb) in volts. Current (I) is how much charge flowing past a point in a circuit in a second (charge/coulombs per time) in amperes. Resistance is how much flow is impeded in ohms Ω. Total potential energy $U = qV$, and power $P = \frac{q\Delta V}{t} = I\Delta V$ in watts (W).

10.2 Resistance

When combining resistors in series (in a line), the total resistance (R_t) with n resistors is $R_t = \sum_{i=1}^{n} R_i$. If the resistors are in parallel, $\frac{1}{R_t} = \sum_{i=1}^{n} \frac{1}{R_i}$.

10.3 Resistivity and Conductivity

Resistivity is slightly different from resistance. Resistivity is a property of a material. A useful formula is $\rho = \frac{RA}{L}$ where R is resistance, A is area of the cross-section of the object in meters squared, and L is the length of the object in meters. ρ is the resistivity in ohm-meters, or Ωm. Electrical conductivity is the inverse of the resistivity, represented as $\sigma = \frac{1}{\rho}$.

10.4 Kirchhoff's Laws

The current flowing in to a node/junction is the same as the current flowing out. In other words, $\sum I_{in} = \sum I_{out}$. The voltage in a circuit follows the rule $\sum v_{rise}$ - $\sum v_{drop} = 0$.

11 Optics

11.1 Light

Light is an EM (Electromagnetic) wave containing energy. Light is made of photons. Different color is from different frequencies (Red = low energy/frequency, blue/purple = high energy/frequency). $E = \hbar f$. (Higher frequency = more energy). $c = \lambda f$ (Speed of light = wavelength * frequency). $c = 3 \times 10^8$m/s. However, the speed of light can slow down in other materials such as water and glass. $v =$ speed of light in a material, $n = \dfrac{c}{v}$ where n is the refractive index (note that $n \geq 1$).

11.2 Law of Reflection

Angle of incidence = angle of reflection ($\theta_i = \theta_f$). The ray coming in will have the same angle going out relative to the normal line (perpendicular to the surface).

11.3 Refraction and Snell's Law

When going from one material into another, the direction and speed of light will change. $n_1 \sin\theta_1 = n_2 \sin\theta_2$ where n_1 is the incident index, n_2 is the refracted index, θ_1 is the incident angle, and θ_2 is the refracted angle (relative to normal line). Going from low refractive index to high refractive index = more close to normal line.

11.4 Diffraction and Interference

Diffraction = light going through a pinhole will go outwards in all directions.
Interference = Two waves add or subtract their intensity (Constructive or destructive).

11.5 Mirrors

11.5.1 Plane mirrors

Just follow law of reflection ($\theta_i = \theta_r$ angle of incidence = angle of reflection). Assume the light comes from point A, imagine point A' reflected across the plane mirror, and the light bouncing off the mirror from point A is just the light that would come from point A'. Point A' is the image of point A.
Rules:

1. $|d_o| = |d_i|$

2. Upright image
3. Virtual image
4. $h_o = h_i$, so magnification ($M = \frac{h_i}{h_o} = 1$).

11.5.2 Concave mirrors

The inside of a spoon (converging). d_o is object distance from mirror. d_i is image distance from mirror. (returning is positive) f is distance between focus and mirror ($f > 0$). h_o is the height of the object. h_i is the height of the image.
$R = 2f$ where R is the radius of the mirror (if you continue the mirror into a circle).
Typical rays:

1. focal ray - ray from focal point will reflect into parallel direction.
2. parallel ray - pass through focus after reflection. (focal ray in opposite direction)
3. center ray - returns back in same direction

Some equations:

1. $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$
2. $\frac{h_i}{h_o} = -\frac{d_i}{d_o} = m$

A real image is inverted, a virtual image is not.

11.5.3 Convex mirrors

Bulging mirror, outside of a spoon (diverging). $f < 0$.
Same equations:

1. $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$
2. $\frac{h_i}{h_o} = -\frac{d_i}{d_o} = m$

The resulting image will always be virtual, upright, and smaller.

11.6 Lenses

Lenses are transparent objects that use refraction to form images.

11.6.1 Converging Lens

Also known as convex lens (opposite of mirrors), they converge to real focus. All parallel rays will pass through focus point ($f > 0$). Rays through a focus end up as parallel, rays through the center of the lens don't change direction, and parallel rays pass through the focus on the other side. Same equations as mirrors:

1. $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$
2. $\frac{h_i}{h_o} = -\frac{d_i}{d_o} = m$

11.6.2 Diverging Lens

Also known as concave lens (opposite of mirrors), they diverge light from a virtual focus. Parallel rays come out as straight lines from the focus, a ray through the center isn't affected.

12 Magnet Stuff

12.1 Permanent Magnets

Permanent Magnets = normal everyday fridge magnets. Every magnet has two sides, north and south. Opposite attract, like repel.

12.2 Magnetic Fields

The loops formed by magnetic fields will be enclosed. Use Right Hand Rule (RHR) to figure out magnetic field generated by currents. The thumb points up in the direction of the current. The four other fingers denote the direction of the magnetic field. The unit of a magnetic field is a Tesla (T). Direction = up, down, left, right, into the page, out of the page (as viewed from a test-taker's perspective). $B_a = \frac{\mu_0 I}{2\pi r}$. B_a is the magnetic field in Tesla, μ_0 is the permeability of free space, which is $4\pi \cdot 10^{-7}$ Tm/A. r is the distance from the measuring point to the wire with current. I is the current in amperes. Note that B is a vector (add + subtract).

12.3 Types of Magnetic Stuff

1. Diamagnetic substances are feebly repelled by magnets.
2. Paramagnetic substances are feebly attracted by a magnet.
3. Ferromagnetic substances are strongly attracted to a magnet (visible with visible eye).

12.4 Loop Currents

Use RHR except inside is same direction, outside is flipped direction.

12.5 What is "Solenoid"

Solenoids are like curly fries with an electric field running through. $B = \mu_0 n I$ where n is the number of turns/loops per meter.

12.6 Magnetic Force on Moving Charges

$F = qVB \sin\theta$.

12.7 Magnetic force between currents

$F_{12} = \frac{\mu_0 I_1 I_2}{2\pi r}$ is force per unit length.