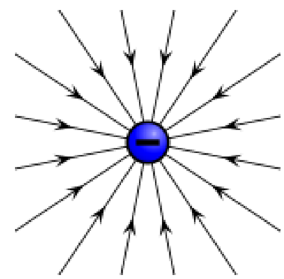
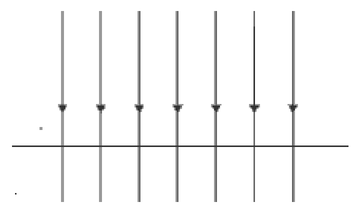
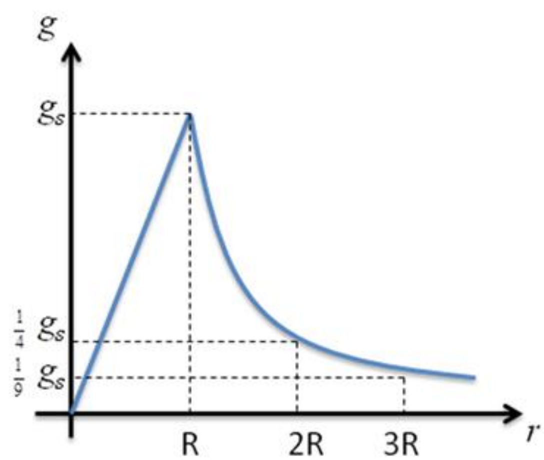
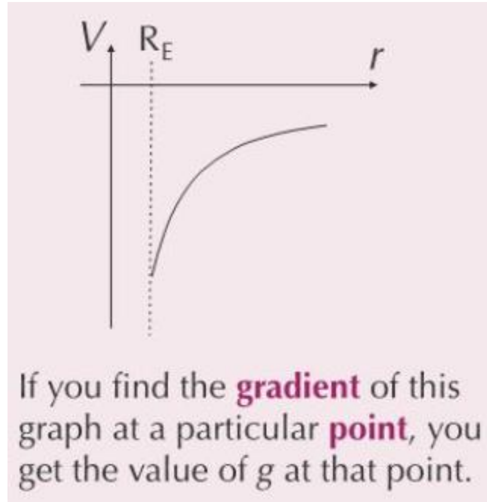
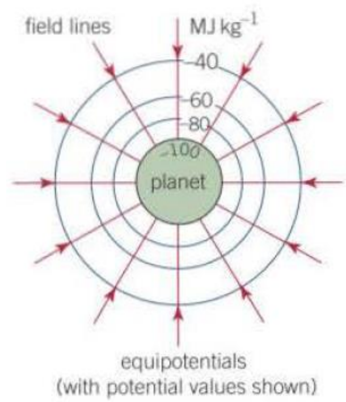
U7 - Fields

Gravitational Fields

What is a field?	An area of space where mass/charge feels a force.
What are the 2 types of fields?ial	• Radial fields:  • Uniform fields:  This is approximately what it looks like at the Earth's surface.
What the equation for Newton's Law of Gravitionation?	$$F = \frac{Gm_1m_2}{r^2}$$ *F is the force between the two objects (N), G is the gravitational constant, m_1 and m_2 are the masses of the two objects and r is the distance between the centre of masses (m).*
What is Gravitational Field Strength and what are the equations for it?	• It is the amount of force something would feel per unit mass (Nkg^{-1}). $$g = \frac{F}{m}$$ *g is the gravitational field strength (Nkg^{-1}), F is the force due to gravity (N), m is the mass of the object (kg).* *This can be rewritten for radial fields:*

	$$g = \frac{GM}{r^2}$$ *g is the gravitational field strength (Nkg^{-1}), G is the gravitational constant, M is the mass of the object (like the Earth rather than the person, although you can do it vice versa) as gravitational field strength is independent of the mass, r is the distance from the centre of mass.*
What 2 assumptions are made in the Gravitational Field Strength equations?	● The mass is very small (called a test mass), otherwise, it'll affect the position of the larger object and thus the position of itself in the field. ● That you're above the surface off the planet as the mass of the planet in the equation has to be below you. *The latter point explains why g decreases as you dig inside a planet.*
What does the Gravitational Field Strength v. Distance graph look like and why?	 The linear relationship at the start is because the mass below you is what matters (between the centre and r). By combining $g = \frac{GM}{r^{2}}$ and $M = \frac{4}{3}\pi r^3\rho$, you get a linear relationship of $g = \frac{4}{3}\pi G\rho r$.
What is Gravitational Potential defined as with its equation?	The gravitational potential energy per unit mass (Jkg^{-1}) at a point OR the work done per unit mass to move an small mass from infinity to a point. $$V = \frac{-GM}{r}$$

	Where V is the the gravitational potential, G is the gravitational constant, M is mass of the object causing the gravitational field, r is the distance to that mass. *This equation is the case as its the area underneath the force-distance graph:* $W = \int_{\infty}^{r} F \, dr$ $= Gm_1m_2 \int_{\infty}^{r} \frac{1}{r^2} \, dr$ $= Gm_1m_2 \left[-\frac{1}{r} \right]$ $E_p = -\frac{Gm_1m_2}{r}$
What is Gravitational Potential Energy defined as, its equation, and why is it negative?	● The work required to move an object from a point to infinity (where there is no potential). $\Delta W = m\Delta V$ *The product of the gravitational potential of a body (Jkg^{-1}) and the test mass.* ● When moving closer to a mass, positive work is done as GPE changes into KE. When moving away, negative work is done as its against the force of gravity (i.e., KE into GPE). *You need to use the furthest reference point for ease of use.*

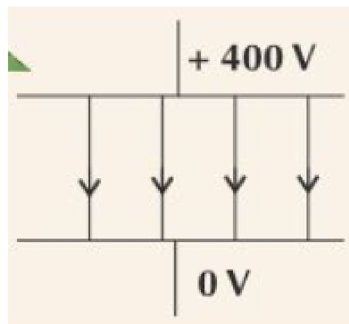
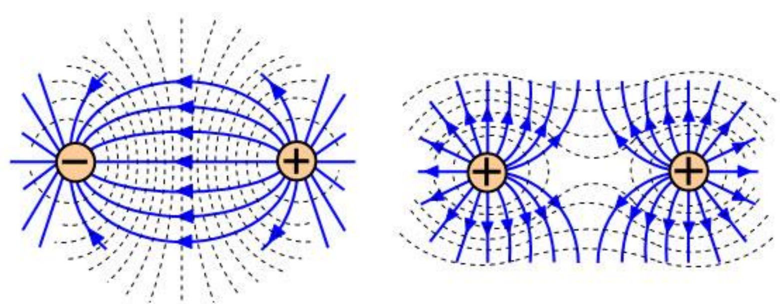
What does the Gravitational Potential v. Radius graph look like?	 *If you find the gradient at a point, you get the value of g as* $g = \frac{-\Delta V}{\Delta r}$ *where the negative sign shows it acting in the opposite direction to gravitational potential.*
What is an equipotential? How as they positioned?	 ● They're points at which gravitational potential or electric potential is constant (you can travel along one with it changing). ● Equal increases of potential are spaced further apart as the field strength decreases so you can move further with the same work done.
What is potential gradient?	● By how much the Gravitational/Electric Potential changes per metre. $$\text{Potential gradient} = \frac{\Delta V}{\Delta r}$$ *E.g., 9.81* $Jkg^{-1}m^{-1}$ *near the surface.*

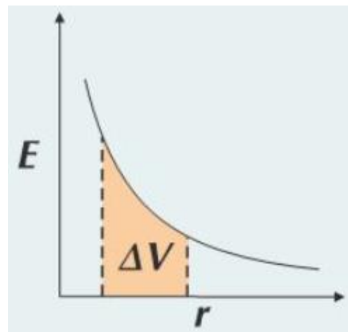
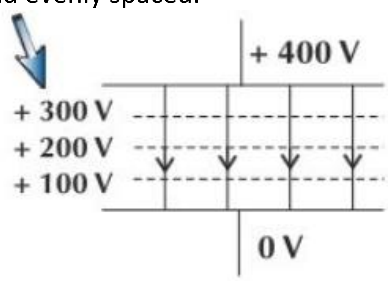
How can the formula for escape velocity be derived?	Set the kinetic energy equal to the gravitational potential energy and solve for v. $$\frac{1}{2}mv^2 \geq \frac{GMm}{r}$$ $$\frac{1}{2}v^2 \geq \frac{GM}{r}$$ $$v \geq \sqrt{\frac{2GM}{r}}$$ $$v \geq \sqrt{2gr}$$ Use $g = \frac{GM}{r}$ to get from the 3rd to 4th line.
What is a synchronous orbit and a geostationary orbit?	• A synchronous orbit is where the orbital period of the satellite is the same as the rotational period of the planet. • A geostationary orbit is synchronous orbit around Earth's equator (thus 24 hours).
What is the energy of a satellite and how does it work in an elliptical orbit?	• The sum of the GPE and KE (which stays constant overall). • Closer to the orbited mass, it speeds up as GPE turns into KE.
Derive the equation for the total energy of an satellite	$$F_{cp} = F_{grav}$$ $$v^2 = \frac{GM}{r}$$ $$E_T = E_K + E_G$$ $$= \frac{1}{2}mv^2 - \frac{GMm}{r}$$ $$= \frac{GMm}{2r} - \frac{GMm}{r}$$ $$= -\frac{GMm}{2r}$$

	Negative energy is used to help account for the conservation of energy. Imagine two masses in a vacuum, as they accelerate towards each other in a vacuum, both kinetic energy and gravitational potential energy increases. Yet, the net energy must be zero so we must make gravitational potential energy negative.
Give a pro and con of low-orbit satellites	+ Closer ∴ cheaper ∴ less powerful transmitters need. - High speeds ∴ constant coverage required.
How can Kepler's Third Law be derived?	By equating the centripetal force and gravitational force and approximating the orbit as a circle. $F_c = F_G$ $m_{sat}\frac{v^2}{r} = G\frac{m_{sat}M}{r^2}$ $v^2 = G\frac{M}{r}$ $\left(\frac{2\pi r}{T}\right)^2 = G\frac{M}{r}$ $\frac{4\pi^2 r^2}{T^2} = G\frac{M}{r}$ $\frac{r3}{T^2} = G\frac{M}{4\pi^2}$ This is only depends on the mass (the proportionality constant differs for the Sun and Earth).

Electric Fields

What is Coulomb's Law?	Force between two point charges (where attractive is negative and repulsive is positive). $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ *Air can be treated as a vacuum thus use ε_0.*
What is Electric Field Strength and its equations in a radial field?	The field strength per unit positive charge (thus, its direction is the direction a positive charge would move)

	$$E = \frac{F}{Q}$$ $$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$
What is a Uniform Electric Field?	A field produced by connecting two parallel plates to opposite poles of a battery. 
How does the electric field strength vary in a uniform field and what is its equation?	It is constant throughout the field. $$E = \frac{V}{d}$$ *Where V is the potential difference between the plates and d is their separation.*
What does an electric field look like between two-like charges and between two-opposite charges?	
What is Electric Potential and its equation?	The work required to move a unit charge from infinity to a point against the electric field.

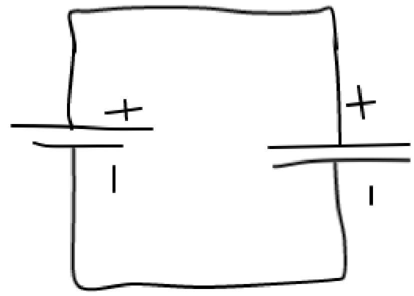
	$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$ Thus… $$\Delta W = Q\Delta V$$ Its change is given by the area under a graph of electric field strength against radius. 
How are the equipotentials different in a uniform field?	They're parallel and evenly spaced.  *The electric field strength is constant throughout, the distance decreases so must the potential difference.*

Capacitance

What is capacitance defined as?	The charge stored for a unit voltage measured in Farads (F). $$Q = VC$$ The capacitance of a capacitor **CANNOT** change.
How does a capacitor become charged?	● Electrons move from the cell to the capacitor ∴ making one side negatively charged.

<table>
<tr>
<td></td>
<td>

- This side repels electrons on the other side making that positive.

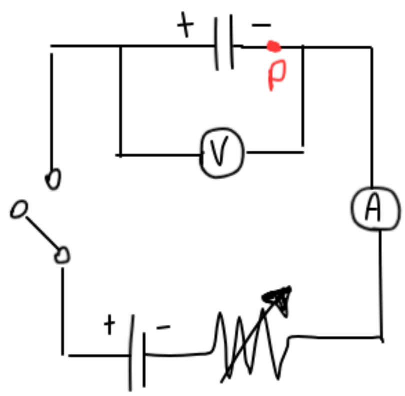


No current [illegible] *llel plates.*

</td>
</tr>
<tr>
<td>

How can you maintain a constant current in a circuit with a capacitor?

</td>
<td>

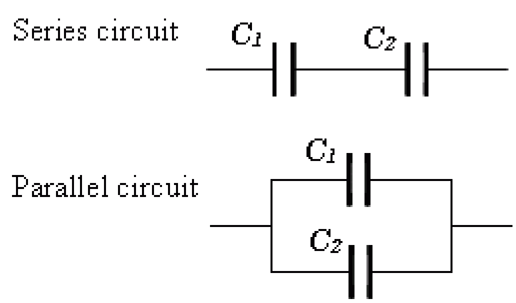


- Without a variable resistor, the current would creases over time as when enough negative charge builds up at P, it will repel incoming.
- With a variable resistor, you can have a high resistance at the start ∴ low current. Yet, when current begins you lower, you decrease resistor to bring it back up.

</td>
</tr>
<tr>
<td>

Derive the equation for capacitors in parallel and parallel

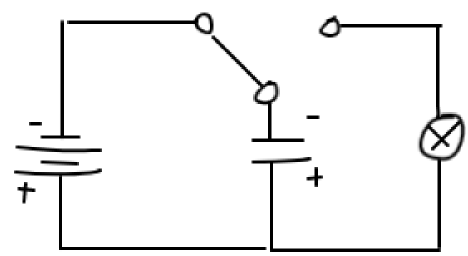
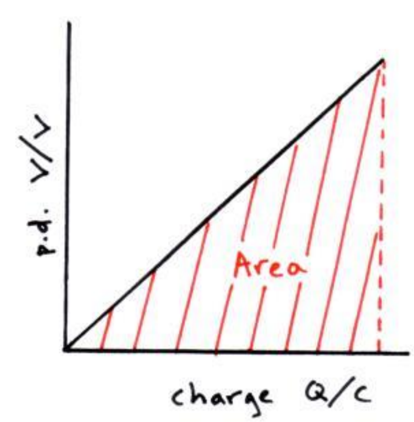
</td>
<td>



This is due to conservation of charge.

For parallel:

</td>
</tr>
</table>

	$$Q = VC$$ $$Q_T = Q_1 + Q_2$$ $$VC_T = VC_1 + VC_2$$ $$C_T = C_1 + C_2$$ For series: $$V_T = V_1 + V_2$$ $$\frac{Q}{C_T} = \frac{Q}{C_1} + \frac{Q}{C_2}$$ $$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$$
Give an example of a use of a capacitor	 Basically, used to store energy for powering bulbs, starting motors, etc. *You can also have a variable capacitor in which you can change the surface area of of overlap to increase capacitance.*
Derive the equation for the energy stored in a capacitor	

<table>
<tr>
<td></td>
<td>

$$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$$

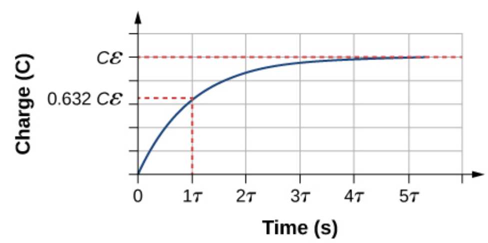
Half the energy is ‘lost’ under resistance. There is no way around this.

</td>
</tr>
<tr>
<td>

What is the charging graph of a capacitor with its equation?

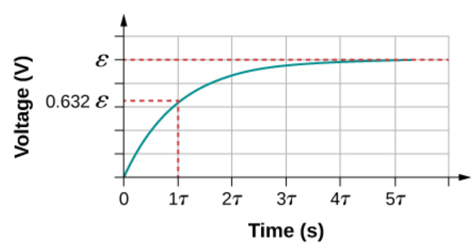
</td>
<td>

Charge vs. Time Capacitor



(a)

Voltage vs. Time Capacitor



(c)

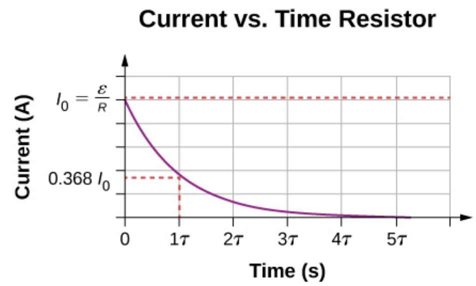
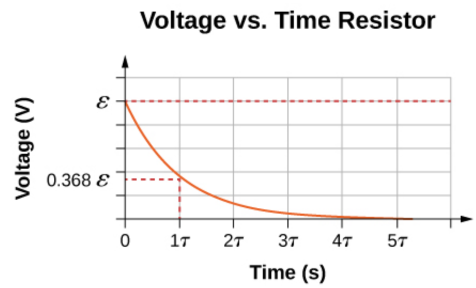
$$Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$$

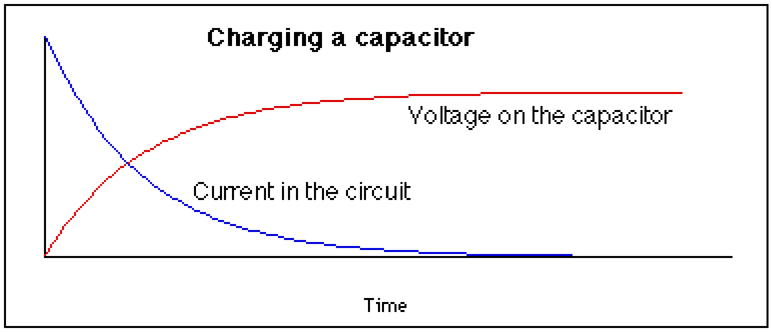
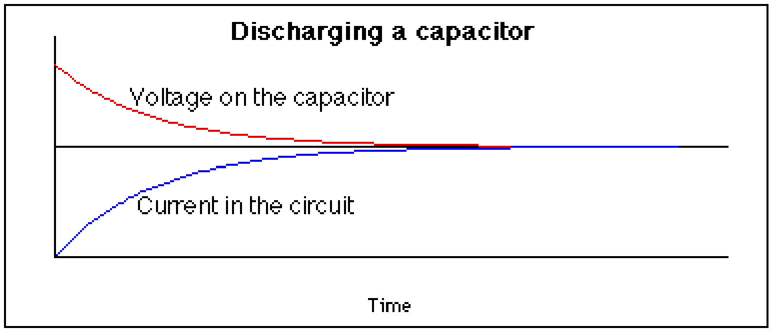
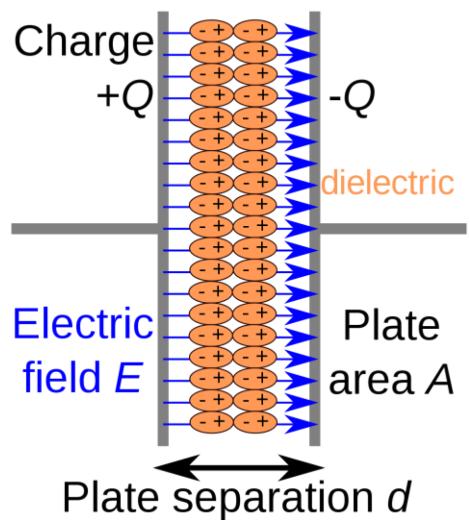
The same can be written replacing Q and Q_0 with V and V_0 respectively.

It tapers off to the emf of the battery because the rate at which charge comes in decreases. (The shape is the same as V = QC where C is a constant).

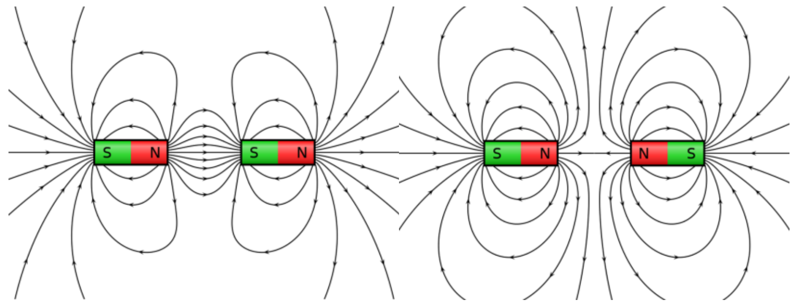
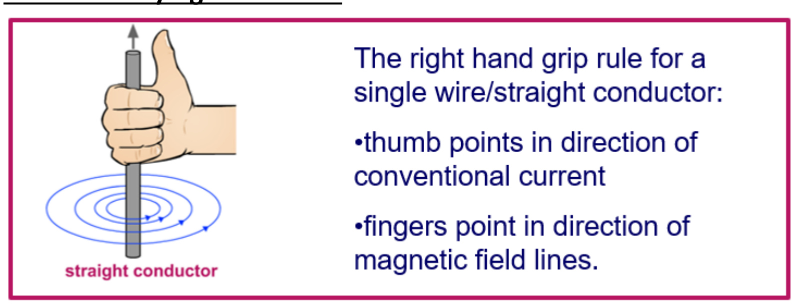
It’s considered fully charged after 5 time constants.

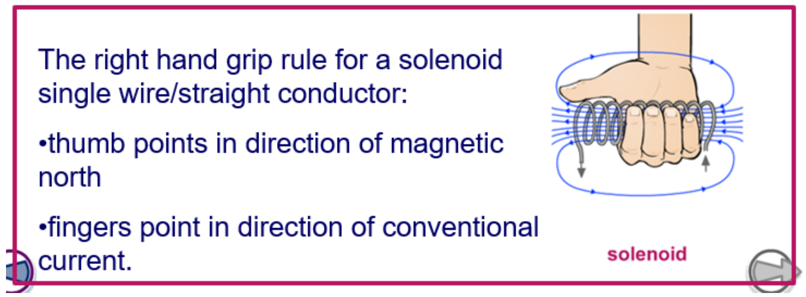
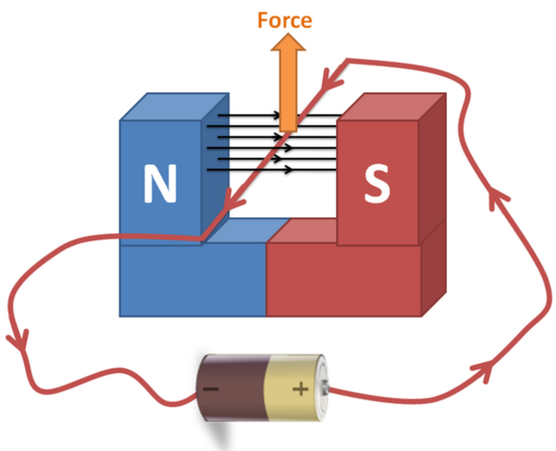
</td>
</tr>
</table>

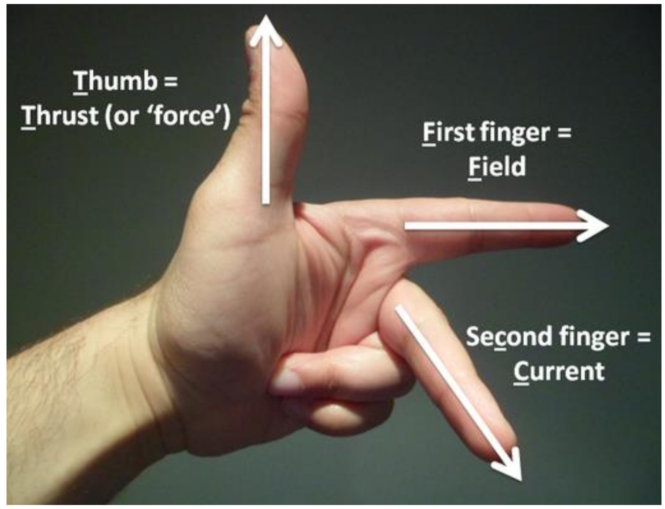
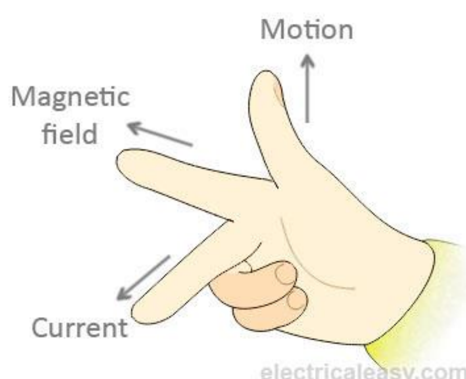
What is the discharging graph of a capacitor with its equation?	 (b)  (d) $$Q = Q_0 e^{-\frac{t}{RC}}$$ *It's considered fully discharged after 5 time constants.*
What is the time constant of a capacitor?	$$\tau = RC$$ ● Where R is the resistance and C is the capacitance of the circuit. ● Increasing T increases the time taken to charge and discharge so current flows for a longer time.
What happens in the 2 cases of charging a capacitor and increasing the separation?	● The capacitance is reduced by the equation C = εA/d. ● If the battery is connected ⇒ constant voltage ∴ energy decreases ∵ $E = ½ CV^2$. ● If the battery is disconnected ⇒ constant charge (cannot leave) ∴ energy increases ∵ $E = ½ Q^2/C$ ∵ work is done to move them apart.
Give a use of capacitors with reason	Camera flashes ∵ it can discharge very quickly.
When will a capacitor break down?	If the dielectric can no longer hold the field.

How does the (dis-)charging current graph compare with the (dis-)charging charge graph? Why?	  ● The charging-current is the derivative of the charging-charge or proportional to charging-voltage.
What is permittivity?	● How difficult it is the generate an electric field in a medium. ● The higher the permittivity of a material, the more charge is needed to generate an electric field of a given size.
How do dielectrics work?	● When charged, polar molecules line up to the electric field. ● Molecules attract more charge onto plates increasing capacitance. 

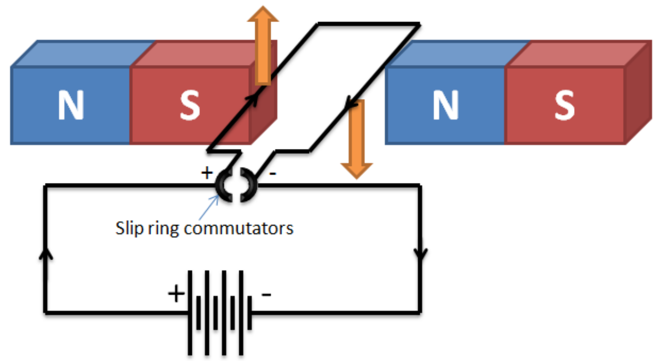
Magnetic Fields

What is a magnetic field?	• A region surrounding a magnetic / current carrying wire which shows the **direction a tiny north pole would move** (hence go north to south).  *They always form loops. They never break or cross so go through the magnetic itself.* *This always means that geographic north pole is actually the magnetic south pole and vice versa.*
What does closer field lines mean?	Greater flux density ∴ greater force on object here.
What is magnetic flux density defined as?	Force per unit length per unit current on a current carrying conductor at **right angles to the magnetic field**. Measured in Tesla (T). $B = \frac{F}{Il}$.
What is the right-hand grip rule and in what 2 cases is it used	**<u>Current-carrying conductor:</u>**  **<u>Solenoid:</u>**

	
What is the motor effect?	The force exerted on a wire when a current passes along a wire in a magnetic field. 
What does the force exerted in the motor effect depend on?	1. The current in the wire and its direction. 2. Strength of the magnet field. 3. Length of the wire. 4. Angle of the wire/current relative to the magnetic field lines. *The greatest force is experience when the wire is perpendicular to the field. No force is experienced when parallel.*

What is Fleming's Left Hand rule? What is it used for?	 ● Thumb = thrust / force. ● First finger = field (going north to south). ● Second finger = conventional current. ● Used to determine the **direction of the force** in the **motor effect** (where current and field are known). *Motor cars drive on left so we remember it as Fleming's left hand rule for motor effect*
What is Fleming's Right hand rule? What is it used for?	 ● Thumb = thrust / force. ● First finger = field (going north to south). ● Second finger = conventional current ● Used for generators (gene<u>**RIGHT**</u>ors). ● Used to determine the **direction of current** in the **dynamo effect** (where force and field are known).

<table>
<tr><td>How is the motor effect used in an electric motor?</td><td>



Current enters loops around leading to an upwards force on side and downwards on the other side.</td></tr>
<tr><td>How can the magnetic flux density?</td><td>

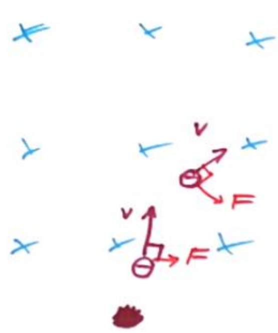
1. Place magnet on balance.
2. Clamp wire in position so magnet can push down.
3. With no current passing through, set balance to zero.

- We know mg = BIl. If we measure mass of 0.05 g, we know current and length then we work out the magnetic flux density.</td></tr>
<tr><td>How are magnetic fields represented in 3D?</td><td>

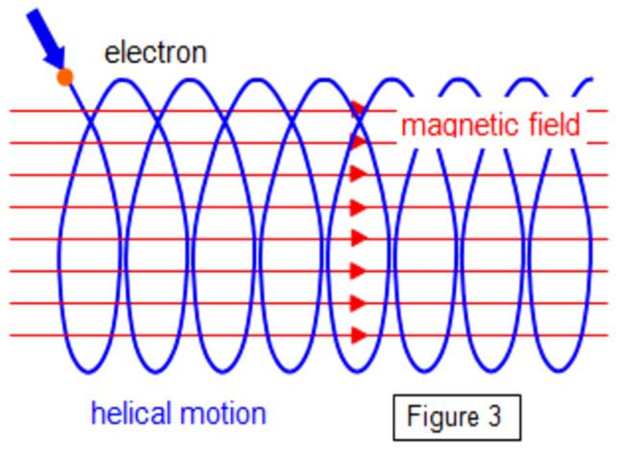
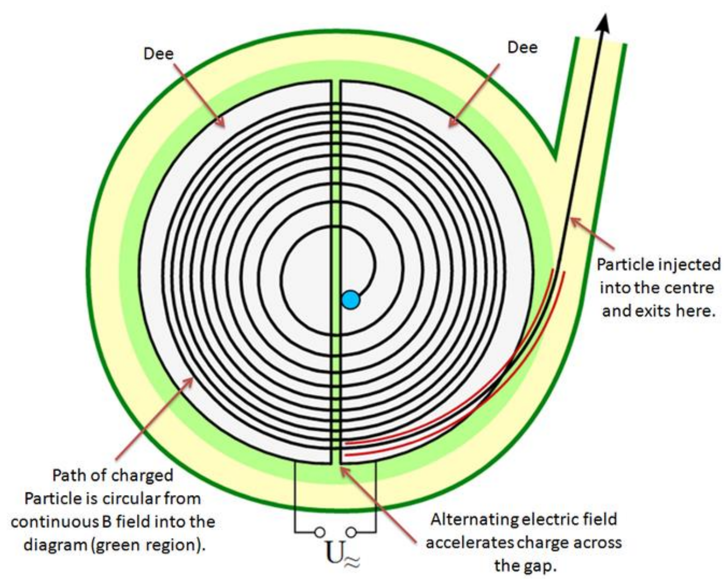
- Using darts.
- Dot (·) - dart coming towards, out of page.
- Cross (X) - dart moving away, into page.</td></tr>
<tr><td>What is the force on a moving charge?</td><td>

$$F = BQv$$

Where the particle is travelling perpendicular to the direction of the magnetic field.</td></tr>
<tr><td>How does Fleming's Left Hand Rule apply to a charge moving in a magnetic field?</td><td>



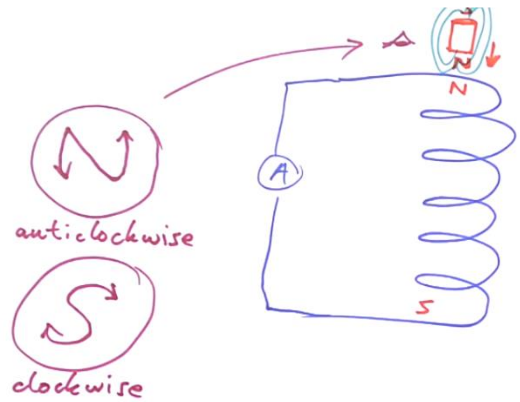
The force is perpendicular to the direction of motion ⇒ circular motion.</td></tr>
</table>

	You have to the careful, current is conventional current - the direction in which a positive charge moves. *And only one component of velocity will be affect (the component within the perpendicular plane).* 
Why do electrons from pair production sometimes move apart?	As it happens in a magnetic field which is stronger than the electric field between them.
What is a cyclotron used to do?	Create beams of high energy protons / electrons for particle accelerators.
How does a cyclotron work?	The electric field flips frequently is such that each time a particle reaches the next 'dee' it is accelerated. 

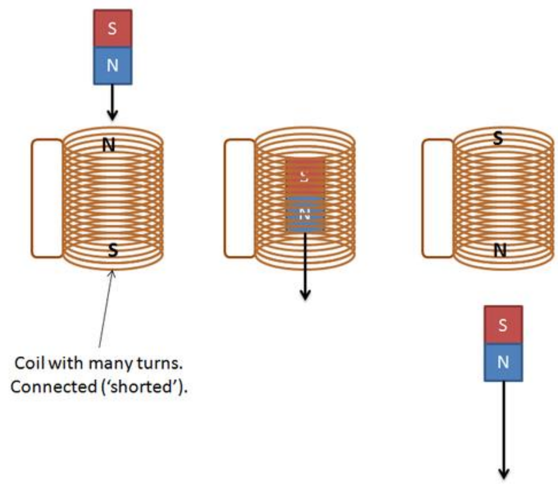
What is the dynamo effect?	● Force produces a current **<u>JUST LIKE</u>** current produces a force. ● It tries to stop the motor effect. ● Eg, when a motor turns then it also produces the Dynamo Effect due to Lenz's Law *This is from many symmetries in physics. It works both ways.*
What is Lenz's Law?	Direction of a current induced by a changing magnetic field is such that the magnetic field created by the induced current opposes the initial changing magnetic field. $\varepsilon = \overset{\text{Lenz's law}}{-} N \frac{\Delta \Phi}{\Delta t}$ *The explanation of this comes from the conservation of energy. Induced current can never be in a direction to help the change that caused it otherwise your producing electrical energy from nowhere.*
What happens when a magnet falls through a solenoid?	1. A magnet entering north-first will induce a current in the solenoid producing a magnetic field that opposes the magnet (Lenz's Law, equal and opposite forces) thus slowing it down. 2. This current flows counterclockwise. 3. It flips direction half-way through. 4. When entering south-last, there's a north pole at the bottom and south at top thus slowing it down.

<table>
<tr>
<td></td>
<td>

5. The current flows clockwise.



Shown also…

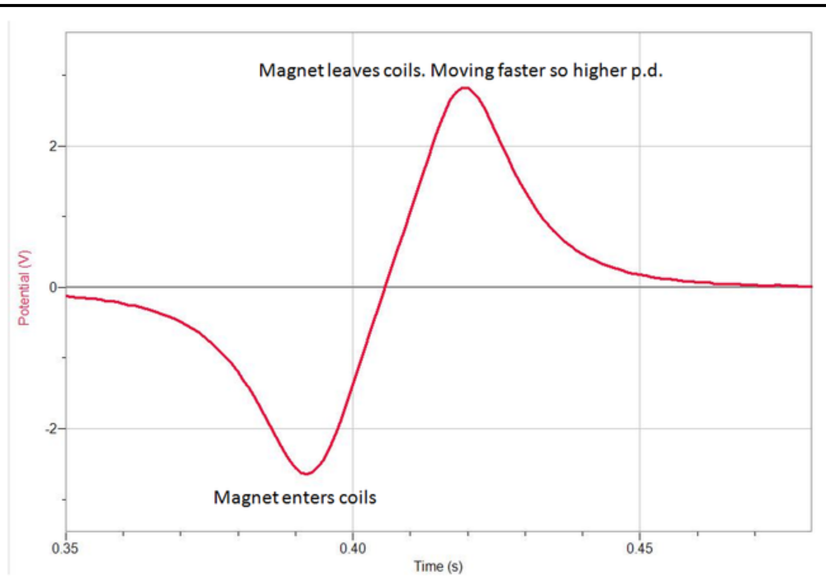


This is to prevent acceleration and thus 'free' energy.

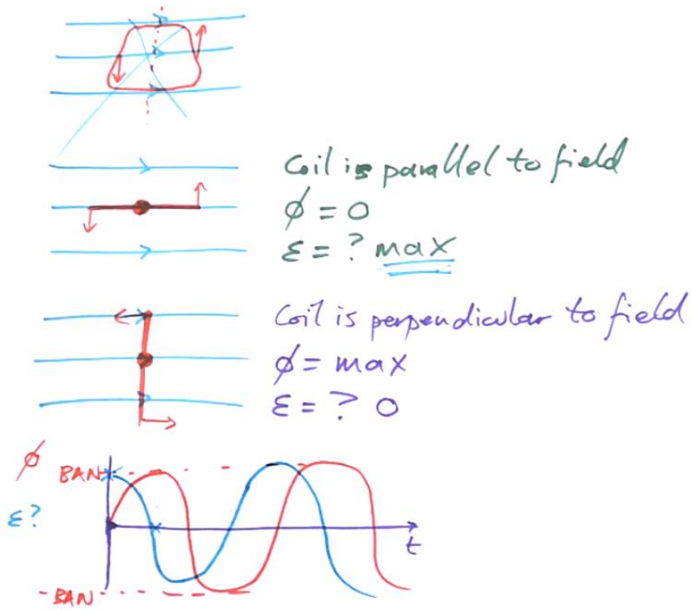
</td>
</tr>
<tr>
<td>

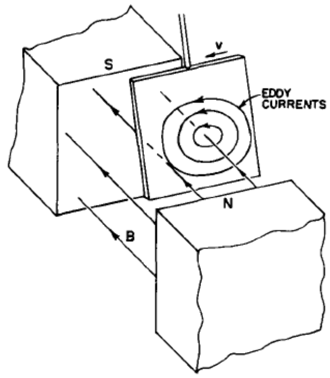
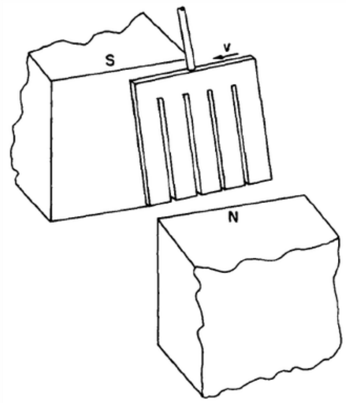
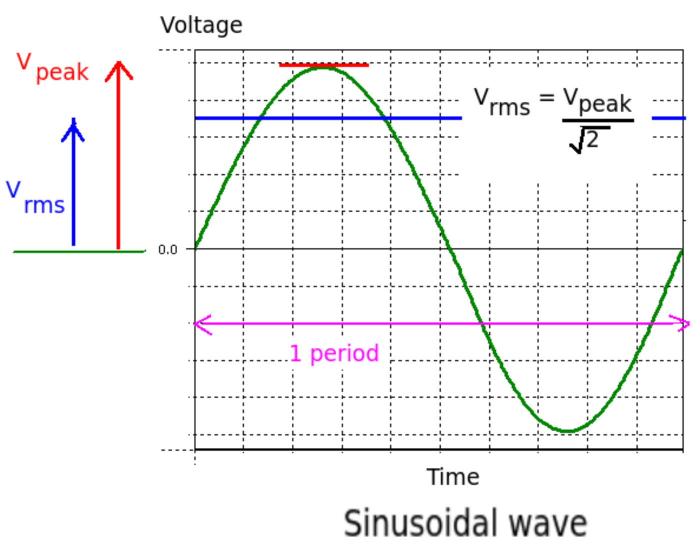
How does the p.d. v. time graph look like for a magnet going via a solenoid?

</td>
<td>



</td>
</tr>
</table>

	It accelerates ∴ moves faster at the bottom ∴ higher pd.
What is induced emf a maximum?	 *Consider the graph carefully here.*
What is Faraday's Law?	Emf induced in a circuit equals rate of change of magnetic flux linkage. Lenz's law $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$
What is an Eddy Current?	A localized electric current induced in a conductor by a varying magnetic field. **<u>Example:</u>**

	 Fig. 16–11. The eddy currents in the copper pendulum.  Fig. 16–12. Eddy-current effects are drastically reduced by cutting slots in the plate. *From Feynman's lectures on physics.* ● The left pendulum is made of a complete sheet of copper allowing eddy currents to flow generating a magnetic field which opposes the motion of the pendulum thus slowing it down. ● The right pendulum has slits, reducing possibility of eddy currents thus less opposition to motion. This one will swing for longer.
What is RMS Voltage?	 ● This is the DC Equivalent of the AC voltage. ● The sine wave in the UK is 50 HZ.
How are transformers designed to be efficient? Why?	1. Low-resistance cable windings to reduce heating effect of current.

	2. Laminated core consisting of layers of iron separated by layers of insulator to reduce eddy currents (making magnetic flux as high as possible and reducing heating). 3. 'Soft iron' core which is easily magnetised and demagnetised to reduce power wasted through repeated magnetisation and demagnetisation.
Why are transformers used?	As transmission over long distances is more efficient as high voltages than low ∵ power is constant and current leads to heating.