A Level Physics Online

OCR B Physics – H557

Module 6: Field and Particle Physics

You should be able to demonstrate and show your understanding of:	Progress and understanding: 1	2	3	4
6.1: Fields (Charge and Field)				
Field: A potential gradient				
Field Strength: Indicates the force applied to interacting particles				
Uniform Field: Field lines are parallel, same force applied to interacting particles everywhere (Field lines point from positive to negative)				
Electric Field Strength, E (Units: NC^{-1} or Vm^{-1}): The force per unit charge at a point exerted on a positive charge at that point; $$E = \frac{F}{q}$$ For a negative charge, the force acting on the charge opposes he direction of the field lines				
Electric Field between Two Plates: Parallel plates can be set up and a potential difference applied to create a uniform electric field. Two factors affect electric field strength; distance between the plates (d) and the potential difference between the plates (V) hence; $$E \propto \frac{1}{d} \text{ and } E \propto V$$ $$E = -\frac{V}{d}$$ The negative sign arises since E-fields are vector fields. The force on the charges present in the field will act to oppose the field's direction. Often this does not matter, and the magnitude of the field is just quoted Note: This equation can only be used for uniform fields. For non-uniform fields (curved field lines) $E = -\frac{dV}{dr}$ is used where r is the distance measured along the field line to the point concerned				
Equipotentials in Electric Fields: Recall from gravitational fields that equipotentials link points of equal potential and equipotentials are always perpendicular to the fields lines. So, at the edges of the parallel plates situation above, the equipotentials 'bow out' because the field lines begin to curve at the edges, creating a non-uniform field near the ends of the plates				

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Millikan's Oil Drop Experiment: In 1897, J.J. Thomson measured the charge-mass ratio of the electron. In 1913 Robert Millikan measured the charge on the electron, so now its mass could be deduced. 1) The equipment is set up with two horizontal parallel plates a distance 'd' apart. A potential difference, V, is applied across the plates so the upper plate is positive and lower is negative. The upper plate has a small hole in the middle of it. A microscope is placed such that it can view the area between the plates 2) Oil is sprayed through the hole in the upper metal plate, droplets of oil fall in view of the microscope (Note: Charge on the oil droplets can be changed by ionising the air between the plates using a weak radioactive source) 3) The spraying charges the droplets to be positive or negative 4) The p.d. applied across the plates results in a uniform field 5) The direction and magnitude of the p.d. is adjusted so a droplet of oil is suspended by equal and opposite uniform gravitational and electric fields between the plates 6) Once the p.d. to hold the droplet stationary is found, the power supply is switched off 7) The droplet then falls, as it is very tiny it rapidly reaches constant (terminal) velocity in the air 8) The droplet is timed over a certain distance (e.g. between two fiducial markers), the viscosity of the air is used to calculate the radius of the droplet. Density of the oil is known so the mass of the droplet can be found 9) By Newton's 3rd, $qE = mg = F \ \textit{where q is the charge on the droplet}$ $$E = \frac{V}{d} \quad \therefore \quad qE = \frac{qV}{d} = mg \quad \therefore \quad q = \frac{mgd}{V}$$ 10) $q = ne$ where q is the charge on the droplet, n is the factor that scales e, and is the charge on the electron. Thousands of values were found, all multiples of 1.6 x 10^{-19}C, so it was deduced that e = -1.6 x 10^{-19}C (as the gravitational force acting downward had to be balanced by another force acting upwards, toward the positive plate, so the charge must be negative)				
Force on a Charge Between Two Plates: $$E = \frac{V}{d} = \frac{F}{Q} \rightarrow F = QE = \frac{QV}{d} \rightarrow F = \frac{QV}{d}$$				
Deflecting Beams of Charged Particles: In Millikan's experiment, the E-field is parallel to the velocity of the droplet. We can used a different setup to show what happens when the E-field is perpendicular to the velocity. The 'deflection' plates are still horizontal a distance d apart with the upper plate being positive; but this time there is an electron gun to the left of the plates where the electrons are accelerated. 1)Electrons are released from the hot cathode (negative) by thermionic emission and are accelerated towards the anode (positive) at the other end of the electron gun. P.T.O.				

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2) The gain in kinetic energy is equal to the potential energy drop between the cathode and the anode; $\frac{1}{2}mv^2 = eV_{gun}$ where e is the charge on an electron and V_{gun} is the 'accelerating p.d.', the voltage applied between the cathode and anode of the electron gun (Also recall, $V = \frac{W}{Q}$) 3) Once the electrons have left the electron gun (once they have passed the anode) they move with a constant velocity as there is no longer any horizontal force acting on them; in the vertical direction there is the constant weight force pulling the electrons downwards 4) Once between the deflection plates the electrons are in a uniform field of strength $E = \frac{V}{d}$. The field lines point downwards (positive to negative plate), the electrons experience a force, $F = qE = (-e)E = -eE$, negative sign shows it is opposing the E-field direction, so F points upwards.				
Force and Motion of the Electron Between the Deflection Plates: - The force, F, arises due to the electron's charge and is constant throughout the uniform field. The electron follows a parabolic path towards the positive plate. Once the electrons leave the field (pass beyond the plates) they follow a straight path - The force acting on the electron due to gravity compared to that due to the electrostatic attraction to the positive plate is very small (i.e. the electron falls a tiny distance compared to the distance risen) so the gravitational effect can be ignored. This applies for cathode ray tubes (electron deflection tubes).				
Particle Constrained in a Wire: If a wire carrying a current cuts across a magnetic field, a force acts on it. The charges forming the current are moving so each electron in the wire is pushed to one side. The sum of all these forces is the resultant force on the wire. 1)The total force on the wire is $F_{TOT} = F_{charge}N$ (where F_{charge} is given by $F = qE$ and N is the number density of the electrons in the wire) and $F_{TOT} = BIL$ 2) For a wire of length, L, we can say; $v = \frac{L}{t} \rightarrow \quad t = \frac{L}{V}$ 3) The total charge, Q, flowing out of length L in a time t is; $Q = Nq$, where q is the charge on one of the moving particles, in this case q = e. Recall also that $Q = It$, hence; $Nq = It \rightarrow \quad Nq = \frac{IL}{v} \quad As\ F_{TOT} = BIL \rightarrow \quad F_{TOT} = NqvB$ $Also\ as\ F_{TOT} = F_{charge}N \rightarrow \quad F_{charge} = qvB$ P.T.O.				

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Particles in Beams – Centripetal Force: In a beam, all charges move independently, and each charge experiences a force ($\frac{mv^2}{r}$) perpendicular to its velocity, hence each charge moves in a circle. The centripetal force in particle accelerators is caused by $F = qvB$ (analogous to gravitational attraction), where q = e, the charge on one electron, hence; $$Bev = \frac{mv^2}{r} \rightarrow \quad Be = \frac{mv}{r} \rightarrow \quad \frac{Br}{v} = \frac{m}{e}$$ This is the mass-charge (m/z) ratio for an electron. We can go further to derive an expression for the particle's momentum; $$\frac{Br}{v} = \frac{m}{e} \rightarrow \quad r = \frac{mv}{Be} \rightarrow \quad r = \frac{p}{Be} \rightarrow \quad p = Ber$$				
Particle Accelerators: Electric fields accelerate the particles in several stages, with each electrode pair increasing the kinetic energy of the particles. To achieve the correct kinetic energy the particles are accelerated in a circular accelerator. To make the particles follow this circular path, very strong magnetic fields are used				
Coulomb's Law: $$F_{electric} = \frac{kQq}{r^2}$$ -In words; any two point charges exert an $F_{electric}$ on each other that is proportional to the product of their charges and inversely proportional to the square of the distance between them. - If the two charges involved are opposite in sign, the value of $F_{electric}$ is negative which indicates that the force is attractive. If the charges have the same sign, the value of $F_{electric}$ is positive which indicates that the force is repulsive. (Note: This equation only applies for radial fields).				
Electric Field Strength: As we know that $E = F/q$ we can say that for a radial field; $$E = \frac{F_{electric}}{q} = \frac{kQ}{r^2}$$ - Where Q is the E-field source - For N field lines spreading out form a point charge Q, at a distance r from the central charge they will meet a sphere of radius r and surface area $4\pi r^2$, so the 'density' of the field lines and hence field strength is given by $\frac{N}{4\pi r^2}$. As we know $N \propto Q$, field strength, $E \propto \frac{Q}{r^2}$				
The value of k: The electric force constant, it has a value of $8.98 \times 10^9 Nm^2C^{-2}$. It is often written as $k = \frac{1}{4\pi\varepsilon_0}$ where ε_0 is the electrical permittivity of free space with value $8.85 \times 10^{-12} Fm^{-1}$. It arises from the analysis of electric fields inside a simple capacitor, the derivation does not need to be known for this course.				

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Inverse Square Laws and Point Sources: Whenever a conserved quantity spreads out from a point its ‘strength’ will follow an inverse square law. For electric and gravitational fields, the spacing between lines indicates the field strength, more spacing indicates a weaker field				
Electrical Potential Energy: To apply a force, work must be done where W = Fd, where F is given by Coulomb’s Law and the type of work done in this case is a potential energy, hence; $E_P = F \times r = \frac{kQq}{r^2} \times r \;\rightarrow\; E_P = \frac{kQq}{r}$ From this we can define electrical potential energy as the energy required to move a point charge from infinity (zero potential energy) to a distance, r				
Electrical Potential, V (Units: JC^{-1}): From above this is defined as the energy per charge, the same definition as potential difference (voltage). $E = \frac{V}{d} = \frac{F}{q} \;\rightarrow\; Vq = Fd \;\rightarrow\; Vq = W \;\rightarrow\; V = \frac{E_P}{q} \;\rightarrow\; V = \frac{kQ}{r}$ -The difference in electrical potential ΔV_{elec} between two points is the same quantity as the potential difference between two points in an electrical circuit				
Radial Electric Field Equations Summary: $F = \frac{kQq}{r^2} \quad E = \frac{kQ}{r^2} \quad E_P = \frac{kQq}{r} \quad V = \frac{kQ}{r}$				
Vectors and Scalars: -Electric field strength, E, and electric force, F, are vector quantities -Electric potential, V, and electric E_P are scalar quantities -Consider an arrangement of two positive point charges, q_1 and q_2 each a distance r from their midpoint. At the midpoint, the E-fields are in opposite directions. If $q_1 = q_2$ then $E_1 = E_2$ and $E_{net} = 0$ at the midpoint. Potential is a scalar, so; $V_{net} = \frac{kq_1}{r} + \frac{kq_2}{r}$ -Consider an arrangement of one positive charge, q_1, and one negative charge, q_2. Each a distance r from their midpoint. At the midpoint, the E-fields are in the same direction, so $E_{net} = E_1 + E_2$, however q_2 is negative, so; $V_{net} = \frac{kq_1}{r} - \frac{kq_2}{r} = 0 \;\; for\; q_1 = q_2$				
Graphically Showing Field Strength: For a graph of E against r, the potential difference is given by the area between the curve and the x-axis.				
Graphically Showing Potential: For a graph of V against r, the field strength at a distance, r, from the centre is given by the gradient of the graph.				

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Graphs of F, E_P and r: The area of an F-r graph gives E_P The gradient of an E_P-r graph gives F				