Mark schemes

1 (a) (i) force per unit charge **(1)**
acting on a positive charge **(1)**

(ii) vector **(1)**

3

(b) (i) $F\left(=\frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}\right)=\frac{4.0\times10^{-9}\times8.0\times10^{-9}}{4\pi\times8.85\times10^{-12}\times(80\times10^{-3})^2}$ **(1)**

$=4.5(0)\times10^{-5}$N **(1)**

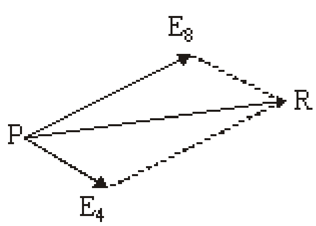
(ii) (use of $V=\frac{Q}{4\pi\varepsilon_0 r}$ gives) $0=\left(\frac{4.0\times10^{-9}}{4\pi\varepsilon_0 x}\right)-\left(\frac{8.0\times10^{-9}}{4\pi\varepsilon_0(80\times10^{-3}-x)}\right)$

or $\frac{4}{x}=\frac{8}{80-x}$ **(1)**

x = 26.7mm **(1)**

4

(c) correct directions for E_4 and E_8 **(1)**
E_8 approx twice as long as E_4 **(1)**
correct direction of resultant R
shown **(1)**



3

[10]

2 (a) (i) $E\left(=\frac{V}{d}\right)=\frac{1400}{15\times10^{-3}}$ **(1)** $\left(=9.3\times10^{4}\,\text{Vm}^{-1}\right)$

(ii) $t\left(=\frac{l}{v}\right)=\frac{30\times10^{-3}}{3.2\times10^{7}}=9.38\times10^{-10}$ s **(1)**

(iii) $ma_y=Ee$ **(1)**

$ay=\frac{9.3\times10^{4}\times1.60\times10^{-19}}{9.11\times10^{31}}$ **(1)** (= 1.64×10^{16} m s^{-2})

acceleration is upwards [or towards + plate]**(1)**

5

(b) v_y (= $a_y t$) = $1.64 \times 10^{16} \times 9.38 \times 10^{-10}$ **(1)** (= 1.54×10^{7} m s^{-1})

$v = \sqrt{(1.54 \times 10^7)^2 + (3.2 \times 10^7)^2}$ = 3.55×10^7 m s^{-1} **(1)**

at $\tan^{-1}\left(\frac{1.54}{3.2}\right) = 26°$ above the horizontal **(1)**

3

[8]

3 (a)

quantity	SI unit	
(gravitational potential)	J kg^{-1} or N m kg^{-1}	scalar
(electric field strength)	N C^{-1} or V m^{-1}	vector
(magnetic flux density	T or Wb m^{-2} or N A^{-1} m^{-1}	vector

6 entries correct **(1) (1) (1)**
4 or 5 entries correct **(1) (1)**
2 or 3 entries correct **(1)**

3

(b) (i) $mg = EQ$ **(1)**

$E\left(\frac{mg}{Q} = \frac{4.3 \times 10^{-9} \times 9.81}{3.2 \times 10^{-12}}\right)$ = 1.32×10^4 (V m^{-1}) **(1)**

(ii) positive **(1)**

3

[6]

4 (a) $mg = T \cos 6$ **(1)**
$F = T \sin 6$ **(1)**
hence $F = mg \tan 6$ **(1)**
[or correct use of triangle:
(1) for sides correct, **(1)** for 6°, **(1)** for tan 6 = F/mg

or $F\Delta x = mg\,\Delta h$, $\tan\theta = \frac{\Delta h}{\Delta x}$ $\tan 6° = \frac{F}{mg}$

3

(b) (i) (use of $E = \frac{V}{d}$ gives) $E = \frac{4200}{60 \times 10^{-3}} = 7.0 \times 10^4$ V m^{-1} **(1)**

(ii) (use of $Q = \frac{F}{E}$ gives) $Q \left(= \frac{mg \tan 6}{E}\right) = \frac{21 \times 10^{-4} \times 9.8 \tan 6}{7 \times 10^4}$

$= 3.1 \times 10^{-9}$ C

(allow C.E. for value of E from (i))

3

[6]

5 (a) (i) $E \left(= \frac{Q}{4\pi\varepsilon_0 r^2}\right) = \frac{29 \times 1.6 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times (1.15 \times 10^{-10})^2}$ **(1)**

$= 3.15 \times 10^{12}$ Vm^{-1} (or (NC^{-1}) **(1)**

(ii) $V\left(= -\frac{GM}{r}\right) = (-) \frac{6.67 \times 10^{-11} \times 63 \times 1.66 \times 10^{-27}}{1.15 \times 10^{-10}}$ **(1)**

$= (-)\ 6.07 \times 10^{-26}$ **(1)** – sign and J kg^{-1}

5

(b) arrow pointing to the right **(1)**

1

[6]

6 (a) (i) (use of $E_P = \frac{e^2}{4\pi\varepsilon_0 r}$ gives) $E_P = \frac{(1.6 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 1.0 \times 10^{-15}}$ **(1)**

$= 2.3 \times 10^{-13}$ (J) **(1)**

(ii) E_K at least distance apart = 0

E_K of (each) proton $= 0.5 \times 2.3 \times 10^{-13}$ (J) **(1)**

$= (1.15 \times 10^{-13}$(J)$) = 0.72$ MeV **(1)** (0.719 MeV)

5

(b) (i) uud **(1)**

(ii) $u\bar{d}$ **(1)**

2

(c) (i) Q = –1(e) **(1)**
B = 0 **(1)**

(ii) π^- **(1)**
$\bar{u}d$ **(1)**

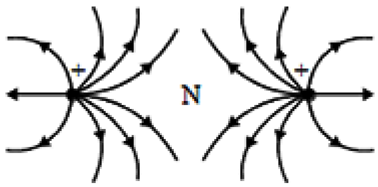
(iii) mass of extra particles produced from total initial kinetic energy **(1)**
extra mass possible in (a) = 1.4 MeV / c^2 **(1)**
pions rest mass in (b) >> extra mass in (a) **(1)**

max 5

[12]

7 (a) (i) force per unit positive charge **(1)(1)**
[force on a unit charge **(1)** only]
vector **(1)**

(ii)



overall correct symmetrical shape **(1)**
outward directions of lines **(1)**
spacing of lines on appropriate diagram **(1)**
neutral point, N, shown midway between charges **(1)**

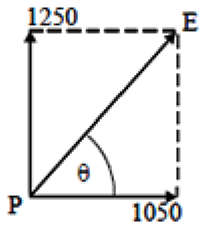
6

(b) (i) $$E_{AP}\left(=\frac{Q}{4\pi\varepsilon_0 r^2}\right)=\frac{2\times10^{-19}}{4\pi\times8.85\times10^{-12}\times(0.12)^2}$$ **(1)**

= 1250 V m^{-1} **(1)**

(ii) $$E_{PB}=\frac{3.0\times10^{-9}}{4\pi\times8.85\times10^{-12}\times(0.16)^2}$$ = 1050Vm^{-1} **(1)**

(iii)



(1)

allow e.c.f. from wrong numbers in (i) and (ii)

$E = \sqrt{1250^2 + 1050^2}$ **(1)** 1630Vm^{-1} **(1)**

$\theta = \tan^{-1}\left(\frac{1250}{1050}\right)$ = 50.0° to line PB and in correct direction **(1)**

max 6

(c) (i) potential due to A is positive, potential due to B is negative **(1)**
at X sum of potentials is zero **(1)**

(ii) $\frac{2 \times 10^{-9}}{4\pi\varepsilon_0(x)} + \frac{-3 \times 10^{-9}}{4\pi\varepsilon_0\,(0.20 - x)} = 0$ **(1)**

gives AX (= x) = 0.080m **(1)** (only from satisfactory use of potentials)

4

[16]

8 D

[1]

9 A

[1]

10 **C**

[1]

11 **C**

[1]

Examiner reports

1 Many candidates appreciated that E is defined as the force acting per unit charge, but very few were able to state that it is the force acting per *mat positive* charge. Consequently in part (a) (i), it was uncommon for more than one of the two available marks to be awarded. Confusion with the definition of electric potential was evident in many candidates' responses. In part (a) (ii), fewer candidates than expected knew that E is a vector quantity.

The Coulomb's law equation was usually correctly recalled at the start of candidates' answers to part (b) (i), and was often followed by an acceptable value for the force. The principal difficulties here included using the wrong constant of proportionality, failing to square the denominator, and not knowing that nano means 10^{-9}. The correct value of 27 mm in part (b) (ii) was usually given after little or no proper explanation, leading to a loss of one of the two marks. Examiners were expecting that something of the form $4/x = 8/(80 - x)$ would be given as a necessary step in the working.

It was clear from their attempts to answer part (c) that a large number of candidates could not follow simple instructions. The direction of the arrows was often wrong, whilst many arrows were not drawn *at P.* The 2:1 length ratio was often correct for the second mark. The third mark was awarded to those candidates who drew an arrow, labelled R, along the correct resultant of two correct component vectors. This final mark was not often awarded.

2 Application of $E = V/d$ and $t = d/v$ brought two straightforward marks for most candidates in the first two parts of (a). Part (iii) caused greater difficulty, often because $F = EQ$ was not known. One incorrect approach, adopted in several scripts, involved assuming a vertical displacement of 7.5 mm, corresponding to half the vertical separation of the deflecting plates. Using $t = 9.4 \times 10^{-10}$ s from part (ii), $a = 2s/t^2$ was then applied, giving a vertical acceleration of 1.7×10^{16} m s^{-2}. The question required candidates to give the direction of the acceleration as well as its magnitude, but this requirement was often overlooked. A few candidates wrote more than they need have done, and in doing so condemned their own answer; 'the acceleration is upwards *in a parabola*'. Confusion between the trajectory and the directions of acceleration and velocity are understandable, but cannot be tolerated in examination answers.

Part (b) was either omitted or answered in a descriptive, non-mathematical way in more than half of the scripts. Those who understood the principles of projectile motion usually had little difficulty in gaining all three marks. A very common mistake however, was attempting to find the new velocity by use of $v = u + at$ with u taken to be 3.2×10^7 m s^{-2}. In the work of the more able candidates, whether the direction of the calculated angle (about 26°) was 'up' or 'down' was often clarified by a diagram.

3 Units of the various physical quantities related to fields and the scalar/vector nature of them, are generally not well known by the candidates. Part (a) showed that the 2004 cohort were no better than their predecessors. Six correct entries in the table were required for three marks, and it was very rare for all three to be awarded. The unit of N m kg^{-1} was accepted as an alternative to J kg^{-1} for gravitational potential, but candidates regularly put N kg^{-1} in the table. The unit of electric field strength was known better, and that of magnetic flux density was usually shown correctly. Candidates often resorted to guesswork when completing the second column of the table. Many did not appreciate that the concept of potential arises from energy considerations and that it is therefore a scalar quantity, whilst the other two quantities are force-related and therefore vectors.

Completely correct answers to part (b) were encountered in many of the scripts. Since the unit of E had already been tested in the table in part (a), no penalty was imposed for wrong or missing units in the answer to part (b)(i). A worrying error, made by a significant minority of the candidates, was to equate the electric force on the particle to its mass, rather than to its weight.

4 It surprised the examiners that only a minority of candidates gained full marks in part (a). Successful solutions were usually based on the triangle of forces. Only the best candidates resolved the tension into components and equated the components to the weight and the electrostatic force respectively. Many candidates incorrectly resolved the weight into components parallel and perpendicular to the thread.

The majority of candidates obtained the correct value of the electric field strength in part (b) and were able to make good progress in part (ii). Candidates who equated g to 10 N kg^{-1} or rounded off incorrectly at the end were penalised. Other candidates attempted inappropriate solutions involving Coulomb's law and did not realise that the force = qE. A small minority of candidates attempted incorrectly to relate the gain of gravitational potential energy to an electrostatic energy formula such as ½QV.

5 There were many pitfalls en route to successful answers to part (a). Most candidates obtained little reward in this question because they could not steer clear of them. Examiners were pleased that so many of the candidates were not put off by the slightly unfamiliar way in which charge was given in part (a)(i), or by the mass given in u in part (a)(ii). This, at least, showed that some learning is taking place across the topic boundaries within Module 4. The really serious problems arose with arithmetic, units and the need to take care in calculations. Typical errors in part (i) were failing to halve the diameter and forgetting to square the denominator. The unit of electric field strength was known by some, yet hardly any of the candidates could give a correct unit for gravitational potential. Carelessness was apparent in the work of all those who omitted the negative sign from the final value for gravitational potential.

The subject area tested in part (a) remains totally confusing for so many candidates, who obviously cannot distinguish between the words gravitational and electric or field and potential. Perhaps they did not read the wording of the question correctly. This may be more excusable than the huge number of wrong answers to the electric field direction in part (c): an arrow pointing inwards at P was common, a tangential arrow at P was fairly frequent, and a vague arrow drawn some distance from P was not exceptional.

6 Few good answers were seen for part (a). Some candidates were unable to calculate the potential energy correctly in part (i), and in part (ii), although the general principle was usually known, candidates often did not realise the question asked for the initial kinetic energy of each proton.

Part (b) was more successful and many candidates scored both marks. However, some sought to include a strange quark in the positive pion.

The majority of candidates scored both marks in part (i) and many gave the correct quark composition in part (ii) although they failed to identify the particle X. In part (iii) only one or two candidates were able to give an adequate answer. Although some candidates stated that the extra mass needed to be created from the kinetic energy of the initial protons, they usually failed to use data to support this statement.

7 Few of the definitions in part (a) included any reference to a positive charge, and “force on a unit charge” seemed more common than the more correct “force per unit charge”. The only field patterns tested in previous PH03 papers have been magnetic ones, so the need here to draw an electric field caught out the vast majority of candidates. Examiners found that almost all of the drawings more closely resembled the field between two current-carrying wires than that between two point charges.

Attempts to answer part (b) were variable and it was not uncommon for candidates having a good understanding of vector addition to score full marks. Misinterpretation of nanocoulomb was a problem for some candidates. The direction of the resultant field caused some difficulty, principally because candidates did not understand the fact that an electric field is directed inwards towards a negative charge.

Only a minority of able candidates showed a clear understanding of the concept of electric potential in part (c). Most answers tried to present arguments which were concerned with field rather than potential. It needs to be more clearly accepted that potential is a scalar quantity and therefore does not have an associated direction; potential values may add to zero but they can never “balance”. In part (c)(ii) there were many intuitive answers of 80 mm, which quoted 3≤ of 200 mm as the reasoning. Credit was given only for answers which were properly reasoned in terms of potential.

10 This question, with a facility of 34.6%, was the most demanding in this test. Actually 68.5% of the students realised that, once the charge on each of X and Y had been increased by +2.0 nC, the force on X would become 2*F*. But practically half of them failed to spot that both charges would now be positive, and the force on X would now be one of repulsion i.e. from Y to X.

11 This question question concerned *E* between two charged parallel plates, where the field strength is constant throughout the region between them. Hence the magnitude of the force on a charge does not vary with the distance across the gap. Just over half of the students chose the correct answer, but almost a quarter of them were tempted by distractor A, showing the force to increase linearly with the distance.