23 Marking scheme: Worksheet (A2)

1 Electric field strength is the force per unit charge at that point. [1]
The potential at a point is the work that must be done to bring unit charge from infinity to that point. [1]

2 **a** $E = \dfrac{V}{d}$, $d = \dfrac{V}{E}$ [1]

$d = \dfrac{5000}{400\,000} = 1.25 \times 10^{-2}$ m $\approx$ 1.3 cm [1]

b $F = EQ = 400\,000 \times 1.6 \times 10^{-19}$ N [1]
$F = 6.4 \times 10^{-14}$ N [1]

3 $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$ so $k = \dfrac{1}{4\pi\varepsilon_0} = \dfrac{1}{4\pi \times 8.85 \times 10^{-12}}$

$k = 8.99 \times 10^9$ m F^{-1} $\approx 9.0 \times 10^9$ m F^{-1} [1]

4 The force between the charges obeys an inverse square law with distance; that is, $F \propto \dfrac{1}{r^2}$ [1]

Point **B**: The distance is the same. The force between the charges is F. [1]
Point **C**: The distance is doubled, so the force decreases by a factor of 4. [1]

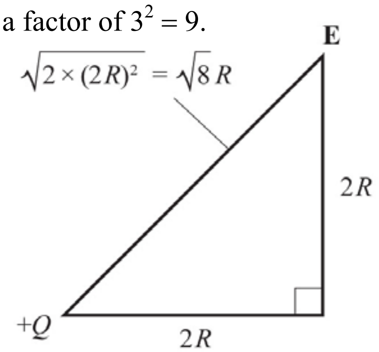
The force between the charges is $\dfrac{F}{4}$. [1]

Point **D**: The distance is trebled, so the force decreases by a factor of $3^2 = 9$. [1]

The force between the charges is $\dfrac{F}{9}$. [1]

Point **E**: The distance between the charges is $\sqrt{8}\,R$. [1]
The force between the charges decreases by a factor of $(\sqrt{8})^2 = 8$ [1]

The force between the charges is $\dfrac{F}{8}$. [1]



5 **a** $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$ [1]

$E = \dfrac{2.5 \times 10^{-6}}{4\pi \times 8.85 \times 10^{-12} \times 0.15^2}$ [1]

$E = 9.99 \times 10^5$ V m^{-1} $\approx 1.0 \times 10^6$ V m^{-1} [1]

b The distance from the **centre** of the dome increases by a factor of 3.
The electric field strength decreases by a factor of $3^2 = 9$. [1]

Therefore $E = \dfrac{1.0 \times 10^6}{9} = 1.1 \times 10^4$ V m^{-1} [1]

6 a i $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$ [1]

$E = \dfrac{20\times10^{-6}}{4\pi\times8.85\times10^{-12}\times0.40^2}$ $\left(r = \dfrac{80}{2} = 40 \text{ cm}\right)$ [1]

$E = 1.124 \times 10^6$ V m^{-1} $\approx 1.1 \times 10^6$ V m^{-1} [1]

ii $E = \dfrac{40\times10^{-6}}{4\pi\times8.85\times10^{-12}\times0.40^2}$ [1]

$E = 2.248 \times 10^6$ V m^{-1} $\approx 2.2 \times 10^6$ V m^{-1} [1]

(The electric field doubles because the charge is doubled, $E \propto Q$.)

b Net field strength, $E = 2.2 \times 10^6 - 1.1 \times 10^6 = 1.1 \times 10^6$ V m^{-1} [1]

The direction of the electric field at **X** is to the left. [1]

7 a $Q = V \times 4\pi\varepsilon_0 r = 20\,000 \times 4 \times \pi \times 8.85 \times 10^{-12} \times 0.15$ [1]

$Q = 3.3 \times 10^{-7}$ C [1]

b $E = \dfrac{kQ}{r^2} = \dfrac{9.0\times10^9\times3.3\times10^{-7}}{0.15^2}$ [1]

$= 1.32 \times 10^5$ V m^{-1} $\approx 1.3 \times 10^5$ V m^{-1} [1]

c $F = eV = 1.6 \times 10^{-19} \times 1.32 \times 10^5$ [1]

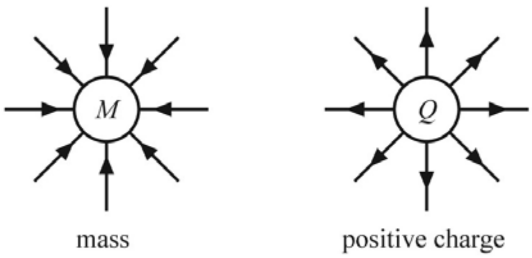
$F = 2.11 \times 10^{-14}$ N $\approx 2.1 \times 10^{-14}$ N [1]

8 a $V = \dfrac{Q}{4\pi\varepsilon_0 r} = \dfrac{kQ}{r} = \dfrac{9.0\times10^9\times-2000\times10^{-9}}{5\times10^{-2}}$ ([1] mark only if minus sign omitted) [2]

$V = 3.6 \times 10^5$ J C^{-1} =360 kV [1]

9 Similarities

- Both produce radial fields. [1]



- Both obey an inverse square law with distance; that is, $F \propto \dfrac{1}{r^2}$. [1]
- The field strengths are defined as force per unit (positive) charge or mass. [1]
- Both produce action at a distance. [1]

Differences

- Electrical forces can be either attractive or repulsive, whereas gravitational forces are always attractive. [1]
- Gravitational forces act between masses, whereas electrical forces act between charges. [1]

10 The electric field strength due to the charge $+Q$ is equal in magnitude but opposite in direction to the electric field strength due to the charge $+3Q$. [1]

Therefore:

$$\frac{Q}{4\pi\varepsilon_0 x^2} = \frac{3Q}{4\pi\varepsilon_0 (R-x)^2}$$ (where R is the distance between the charges = 10 cm) [1]

$$\frac{1}{x^2} = \frac{3}{(R-x)^2}$$ [1]

so $\frac{R-x}{x} = \sqrt{3}$ [1]

$x(1 + \sqrt{3}) = R$ so $x = \frac{R}{1+\sqrt{3}} = 0.37\,R$ [1]

$x = 0.37 \times 10 = 3.7$ cm [1]

11 ratio $= \frac{e^2/4\pi\varepsilon_0 r^2}{Gm^2/r^2}$ (where m = mass of proton and r = separation) [2]

ratio $= \frac{e^2}{4\pi\varepsilon_0 G m^2}$ [1]

The r^2 terms cancel and so this ratio is independent of the separation. [1]

ratio $= \frac{(1.6\times10^{-19})^2}{4\pi\times8.85\times10^{-12}\times6.67\times10^{-11}\times(1.7\times10^{-27})^2}$ [1]

ratio $\approx 1.2 \times 10^{36}$ [1]

12 **a** $F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2} = 9 \times 10^9 \times \frac{1.6\times10^{-19}\times1.6\times10^{-19}}{(10^{-15})^2}$ [1]

$= 230$ N [1]

b $V = \frac{Q}{4\pi\varepsilon_0 r} = 9 \times 10^9 \times \frac{1.6\times10^{-19}}{10^{-15}}$ [1]

$= 1.44 \times 10^6$ V [1]

c $W = VQ = 1.44 \times 10^6 \times 1.6 \times 10^{-19}$ [1]

$= 2.3 \times 10^{-13}$ J [1]

d $\frac{1}{2}mv^2 = W \Rightarrow v^2 = \frac{2W}{m}$ [1]

$v^2 = \frac{2\times2.3\times10^{-13}}{1.7\times10^{-27}} = 2.7 \times 10^{-14}$ [1]

$v = \sqrt{2.7\times10^{-14}} = 1.6 \times 10^7$ m s^{-1} [1]

