Unit 21 · Potential, Potential Difference and Potential Energy

ANSWER KEY · FOR TEACHERS

Full marks 37

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. potential
2. volt
3. scalar
4. equipotential
5. gradient
6. negative
7. electron volt
8. electron gun

K · 4

Each carries 0.5 mark.

2 Label the diagram

1. V/4
2. V/2
3. 3V/4
4. equipotentials dashed

U · 2

Each carries 0.5 mark.

3 Multiple choice

i. **b.** −225 V — A · 1

$V = kQ/r = 9.0 \times 10^9 \times (-5.0 \times 10^{-9}) \div 0.20 = -225$ V: negative near a negative charge.

ii. **c.** zero — U · 1

Its potential energy doesn't change, so the field does no work: the field is at right angles to the equipotential.

iii. **b.** 1.6×10^{-19} J — K · 1

The electron volt is a unit of energy: $e \times 1\ V = 1.6 \times 10^{-19}$ J.

iv. **b.** higher potential, losing potential energy — U · 1

A negative charge is pulled against the field, to higher potential; its potential energy $(-e)\Delta V$ falls, becoming kinetic energy.

v. **b.** 100 V — A · 1

The field is uniform, so V rises steadily: a third of the way across, a third of 300 V = 100 V.

4 Very short answers

a. MARKING SCHEME — K · 1

✓ Work done per unit positive charge moved between the two points ($\Delta V = W/Q$).

b. MARKING SCHEME — U · 1

✓ Negative (work is needed to separate them).

c. MARKING SCHEME — U · 1

✓ No work along an equipotential, so the field has no component along it.

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5 Short answers

a. MARKING SCHEME — U · 2

- ✓ Both of the bird's feet are on the same wire, at (almost) the same potential: no potential difference across its body.
- ✓ With no p.d., no current flows through it.

b. MARKING SCHEME — U · 2

- ✓ Any two similarities, e.g. both act without contact, have infinite range, obey inverse-square laws (1 mark for both).
- ✓ Any two differences, e.g. gravity only attracts while electric forces also repel; the electric force is much stronger; electric fields can be shielded; gravity acts on all objects, electric force only on charged ones (1 mark for both).

c. MARKING SCHEME — A · 2

- ✓ Yes: at the midpoint the potentials $+kQ/r$ and $-kQ/r$ add to zero.
- ✓ The field there is not zero: both fields point from the + charge towards the − charge, so they add.

6 Long answer

ANSWER — U · 4

Move a charge +Q a small distance Δx along the field without accelerating it. The field pushes it with EQ, so the outside force is $-EQ$ and does work $W = -EQ\Delta x$. By the definition of potential difference the same work is $Q\Delta V$. So $-EQ\Delta x = Q\Delta V$, and $E = -\Delta V/\Delta x$: the field is minus the potential gradient, pointing the way the potential falls. Its unit is then volts per meter, and $1\ V/m = 1\ (J/C)/m = 1\ N\ m/(C\ m) = 1\ N/C$.

MARKING SCHEME

- ✓ Work by the outside agent against the field: $W = -EQ\Delta x$.
- ✓ The same work is $Q\Delta V$.
- ✓ $E = -\Delta V/\Delta x$, pointing the way V falls.
- ✓ $1\ V/m = 1\ J/(C\ m) = 1\ N/C$.

7 Numerical problems

a. ANSWER — A · 3

Each corner is half a diagonal from the center: $r = 0.20 \times \sqrt{2} \div 2 = 0.141$ m. Potentials add as numbers: $V = k(2.0 + 2.0 - 2.0 + 3.0) \times 10^{-9} \div 0.141 = 9.0 \times 10^{9} \times 5.0 \times 10^{-9} \div 0.141 =$ **318 V**.
$W = qV = 1.0 \times 10^{-9} \times 318 =$ **3.2×10^{-7} J**.

MARKING SCHEME

- ✓ $r = 0.141$ m.
- ✓ $V = k\Sigma Q/r = 318$ V.
- ✓ $W = 3.2 \times 10^{-7}$ J.

b. ANSWER — A · 3

$E_P = kQq/r = 9.0 \times 10^{9} \times 3.0 \times 10^{-6} \times (-4.0 \times 10^{-6}) \div 0.30 =$ **-0.36 J**.
To take them to infinity (where $E_P = 0$), the work needed is $0 - (-0.36) =$ **$+0.36$ J**.

MARKING SCHEME

- ✓ $E_P = kQq/r$ with signs.
- ✓ $E_P = -0.36$ J.
- ✓ Work needed 0.36 J.

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c. **ANSWER** A · 4

i. Kinetic energy = eV = **2.5 keV** = $2500 \times 1.6 \times 10^{-19}$ = **4.0×10^{-16} J**.

ii. $v = \sqrt{(2E_k/m)} = \sqrt{(2 \times 4.0 \times 10^{-16} \div 9.11 \times 10^{-31})}$ = **3.0×10^{7} m/s**.

iii. $v \propto \sqrt{V}$: four times the voltage gives **twice** the speed.

MARKING SCHEME

✓ 2.5 keV = 4.0×10^{-16} J.

✓ $\frac{1}{2}mv^2 = eV$.

✓ $v = 3.0 \times 10^{7}$ m/s.

✓ $v \propto \sqrt{V}$: twice the speed.

8 Think

ANSWER HA · 3

Closely spaced equipotentials mean a large potential gradient, so a **strong field** ($E = -\Delta V/\Delta x$). A positive charge is pushed "downhill", from high potential to low, at right angles to the equipotentials, like a ball down the steepest slope. An electron goes the other way, "uphill" to higher potential, since its potential energy is −eV.

MARKING SCHEME

✓ Close equipotentials: a large potential gradient, a strong field.

✓ A positive charge moves towards lower potential, across the equipotentials at right angles.

✓ An electron moves towards higher potential.

9 Activity: Equipotentials in a tray of water (Activity 21)

(not marked)

WHAT STUDENTS SHOULD FIND

The lines are straight, parallel to the strips and about equally spaced: the potential rises steadily across the tray. The field, the change in voltage ÷ the distance between lines, is about the same everywhere (for example 2 V in 2.5 cm, 80 V/m), as for parallel plates. Near the ends of the strips the lines bend.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	6	14	14	3	**37**

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