OCR A AS Charge and Current solutions

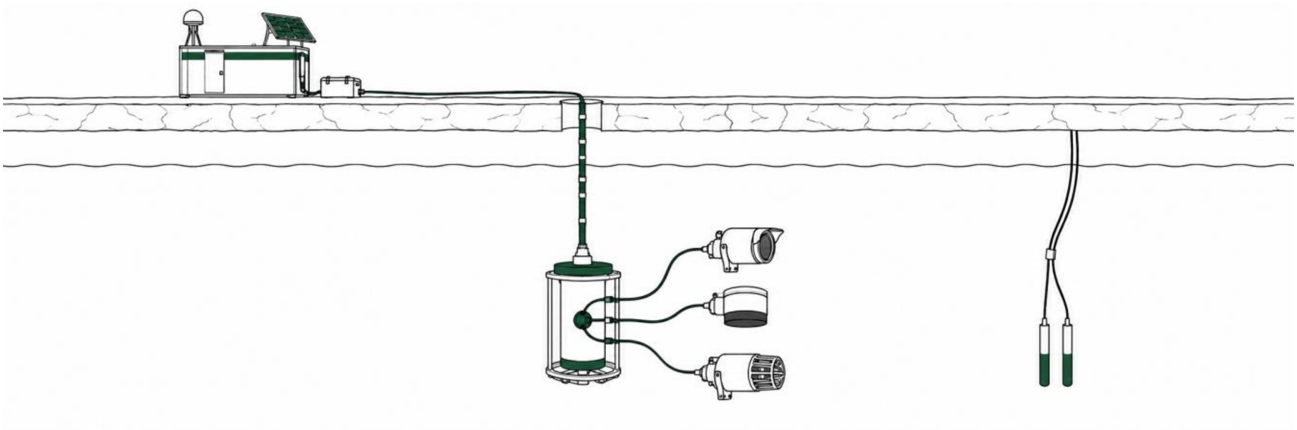
Matching solutions and teaching prompts for the class review

Specification points covered

- 4.1.1(a–d) Define current and the coulomb; use elementary charge and charge quantisation.
- 4.1.1(e–g) Identify charge carriers, compare conventional current with electron flow, and apply Kirchhoff's first law at a junction.
- 4.1.2(a–b) Understand mean drift velocity and use I = Anev.
- 4.1.2(c) Distinguish conductors, semiconductors and insulators using carrier number density.

Teaching focus

Require pupils to distinguish charge, current and the direction of moving charge precisely.
Award calculation marks for the physical method, substitution, direction and unit—not simply the final number.



Context diagram: the surface station, tether, instrument pod and seawater probe.

1. Charge foundations

1. Define electric current and define the coulomb. [2 marks]

Answer / mark points: Electric current is the rate of flow of charge: I = ΔQ/Δt. One coulomb is the charge transferred by a current of 1 A in 1 s; equivalently, 1 C = 1 A s.	
Teacher prompt / common error: Current is not the amount of charge; it is a rate. Define the coulomb through ampere-seconds rather than merely naming its symbol.	

2. A particle on the observatory has charge +4.8 × 10^{-18} C. Calculate the number of electrons transferred and state whether the particle gained or lost them. Use e = 1.6 × 10^{-19} C. [2 marks]

Answer / mark points: N = Q/e = 4.8 × 10^{-18} / 1.6 × 10^{-19} = 30. The positive charge means the particle has lost 30 electrons.	
Teacher prompt / common error: The sign determines gained or lost electrons. A positive object has an electron deficit.	

2. Charge in the tether

3. A sensor reports three possible net charges: $+3.2 \times 10^{-19}$ C, -4.8×10^{-19} C and $+7.0 \times 10^{-19}$ C. Identify which values are physically possible for an isolated object and explain your decision. [2 marks]

Answer / mark points: $+3.2 \times 10^{-19}$ C = +2e and -4.8×10^{-19} C = -3e, so both are possible. $+7.0 \times 10^{-19}$ C is not an integer multiple of e and is therefore not possible as the net charge of an isolated object.
Teacher prompt / common error: Net charge is quantised in integer multiples of e; do not judge a value only by its sign.

4. The observatory tether carries a steady current of 3.6 A for 150 s. Calculate (a) the charge transferred and (b) the number of electrons that pass a cross-section of the tether. [3 marks]

Answer / mark points: (a) $Q = It = 3.6 \times 150 = 540$ C. (b) $N = Q/e = 540 / 1.6 \times 10^{-19} = 3.375 \times 10^{21}$, so 3.4×10^{21} electrons to two significant figures.
Teacher prompt / common error: Calculate charge before dividing by e. The number of electrons is a count and therefore has no unit.

5. The metallic tether is connected to a direct-current supply. Compare the direction of conventional current with the direction of electron drift in the tether. [2 marks]

Answer / mark points: Conventional current is defined as the direction in which positive charge would move. Electrons are negatively charged, so their mean drift is in the opposite direction to the conventional current.
Teacher prompt / common error: Avoid saying that current and electrons both 'flow the same way'. State the two directions explicitly.

3. Current through the observatory

6. A camera switches on almost immediately after the surface supply is connected, even though the mean drift velocity of the electrons is small. Explain why these statements are consistent. [2 marks]

Answer / mark points: Free electrons are already present throughout the tether. Connecting the supply establishes an electric field, and the electrical effect propagates rapidly around the circuit; an individual electron does not have to travel from the surface station to the camera before the camera responds.

Teacher prompt / common error: Do not replace drift velocity with the speed of a single electron. The key idea is a rapidly established field acting on carriers already in the cable.

7. At a junction inside the underwater pod, 6.2 A enters. Currents of 1.8 A and 2.4 A leave through the camera and sonar branches. Calculate the current in the pump branch and explain the law used. [3 marks]

Answer / mark points: Kirchhoff's first law gives total current into the junction = total current out. $I_{pump} = 6.2 - 1.8 - 2.4 = 2.0$ A. This law follows from conservation of charge: charge does not accumulate at a steady junction.

Teacher prompt / common error: The branch currents must sum to the incoming current. Link Kirchhoff's first law explicitly to conservation of charge.

8. During a diagnostic cycle, the tether current has the values shown in the table. Calculate the total charge transferred during the 20 s cycle. [3 marks]

Time interval / s	Current / A
0 to 12	3.0
12 to 20	1.5

Answer / mark points: $Q = \Sigma I\Delta t = (3.0 \times 12) + (1.5 \times 8) = 36 + 12 = 48$ C.

Teacher prompt / common error: Charge is the area under an I–t graph; for constant stages, add $I\Delta t$ for each interval.

4. From moving carriers to current

9. A conductor has cross-sectional area A and carrier number density n. In time Δt, charge carriers with mean drift velocity v move a distance vΔt. Starting from the volume that passes a cross-section, derive I = Anev. **[4 marks]**

Answer / mark points: In time Δt, the carriers move distance vΔt. Volume passing the cross-section = AvΔt. Number of carriers = nAvΔt. Charge transferred is ΔQ = neAvΔt. Therefore I = ΔQ/Δt = Anev.

Teacher prompt / common error: The density n is carriers per unit volume, so multiply it by AvΔt before multiplying by e.

10. The copper tether has cross-sectional area 2.5 × 10^{-6} m^2 and carrier number density 8.5 × 10^{28} m^{-3}. Calculate the mean drift velocity when it carries a current of 7.0 A. **[3 marks]**

Answer / mark points: v = I/Ane = 7.0 / [(2.5 × 10^{-6})(8.5 × 10^{28})(1.6 × 10^{-19})] = 2.06 × 10^{-4} m s^{-1}, so 2.1 × 10^{-4} m s^{-1} to two significant figures.

Teacher prompt / common error: Use the area in square metres and keep every factor inside the denominator.

5. Changing a conductor

11. A short section of the same copper tether has half the cross-sectional area of the rest of the tether. The current is steady. State what happens to the mean drift velocity in the narrower section and explain why the current does not change at the boundary. [3 marks]

Answer / mark points: For the same material, n and e are unchanged. Since $I = Anev$ and A halves while I stays constant, v must double. At steady state, charge cannot accumulate at the boundary, so the rate of flow of charge and hence the current is the same on both sides.
Teacher prompt / common error: Steady current does not mean equal drift velocity when the cross-sectional area changes.

12. Heating a semiconductor sensor increases its carrier number density by a factor of 12. The current and cross-sectional area are kept constant. Determine the factor by which its mean drift velocity changes. [2 marks]

Answer / mark points: From $I = Anev$, with I and A constant, v is inversely proportional to n. Increasing n by a factor of 12 reduces v to 1/12 of its original value.
Teacher prompt / common error: At fixed current, n and v vary inversely; a larger carrier density does not require a larger drift speed.

13. In the seawater probe, positive ions move towards the right-hand electrode and negative ions move towards the left-hand electrode. Explain how both movements can produce conventional current in the same direction. [3 marks]

Answer / mark points: Positive ions moving right produce conventional current to the right. Negative ions moving left also produce conventional current to the right because conventional current is opposite to the motion of negative charge. The two contributions therefore add.
Teacher prompt / common error: A negative charge moving left is equivalent to conventional current to the right.

6. Ionic and solid conductors

14. Use the carrier number densities in the table to identify material A, B and C as a conductor, semiconductor or insulator. Justify your choices using carrier number density. [3 marks]

Material	Carrier number density / m^{-3}
A	8.5×10^{28}
B	3.0×10^{20}
C	less than 1×10^{5}

Answer / mark points: A is a conductor because it has a very large carrier number density. B is a semiconductor because its carrier density is intermediate and appreciably smaller than A. C is an insulator because it has a negligible density of mobile charge carriers.

Teacher prompt / common error: Classify by the density of mobile charge carriers, not by memorised examples of materials.

15. Inside an ionic pump, 2.5×10^{15} singly positive ions move to the right each second while 1.0×10^{15} doubly negative ions move to the left each second. Calculate the magnitude and direction of the conventional current. [4 marks]

Answer / mark points: Positive-ion contribution = $(2.5 \times 10^{15})(1.6 \times 10^{-19}) = 4.0 \times 10^{-4}$ A to the right. Negative-ion contribution = $(1.0 \times 10^{15})(2)(1.6 \times 10^{-19}) = 3.2 \times 10^{-4}$ A to the right. Total conventional current = 7.2×10^{-4} A to the right.

Teacher prompt / common error: The negative ions have charge magnitude 2e and their leftward motion contributes rightward conventional current.

7. Engineering judgement

16. A proposed replacement tether has a carrier number density 100 times smaller than the present tether. Its cross-sectional area and mean drift velocity would initially be unchanged. Evaluate the claim that it will carry the same current, and state one change that could restore the original current. **[3 marks]**

Answer / mark points: The claim is false. $I = Anev$, so reducing n by a factor of 100 while A and v stay unchanged reduces the current to 1/100 of its original value. The original current could be restored by increasing the area by a factor of 100 or increasing the mean drift velocity by a factor of 100; credit either change.
Teacher prompt / common error: Compare factors directly in $I = Anev$. Merely saying 'use a better conductor' does not state a compensating change.

Language and method check

Use 'current increases/decreases/stays constant'; current does not 'speed up'.
Use 'electrons drift opposite to conventional current'; do not describe current as a stream of electrons in an electrolyte.
At a steady junction, conservation of charge means no net charge accumulates.