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

## 1 Spot the error

**ANSWER** U · 3

He used the difference in $n$ as if it were a single $n$. The energy given out is the difference between the two levels' energies: $E_4 = -13.6 \div 16 = -0.85$ eV and $E_2 = -13.6 \div 4 = -3.40$ eV, so $\Delta E = -0.85 - (-3.40) =$ **2.55 eV**.

2.55 eV is more than 1.89 eV, and $\Delta E = h\nu$, so the frequency is **higher** than the red line's.

**MARKING SCHEME**

- ✓ The mistake: the energy is the difference between $E_4$ and $E_2$, not found from the difference in $n$.
- ✓ $\Delta E = -0.85 - (-3.40) = 2.55$ eV.
- ✓ Higher frequency, since 2.55 eV > 1.89 eV and $\Delta E = h\nu$.

## 2 All the jumps

**ANSWER** A · 5

i. $E_1 = -13.60$, $E_2 = -3.40$, $E_3 = -1.51$, $E_4 = -0.85$ eV. Six jumps: 4→3, 4→2, 4→1, 3→2, 3→1, 2→1.

ii. Least: 4→3, $-0.85 - (-1.51) =$ **0.66 eV**. Most: 4→1, $-0.85 - (-13.60) =$ **12.75 eV**. (The levels crowd together as $n$ grows, so the top jump is the smallest.)

iii. $12.75 \times 1.602 \times 10^{-19} = 2.04 \times 10^{-18}$ J. $\nu = \Delta E \div h = 2.04 \times 10^{-18} \div (6.626 \times 10^{-34}) =$ **$3.08 \times 10^{15}$ Hz**.

**MARKING SCHEME**

- ✓ The four energies.
- ✓ The six jumps.
- ✓ Least: 4→3, 0.66 eV.
- ✓ Most: 4→1, 12.75 eV.
- ✓ $\nu = 3.08 \times 10^{15}$ Hz, with the energy changed to joules first.

## 3 Predict, then explain

**ANSWER** HA · 3

It can take in **10.2 eV** (level 1 → level 2: $-3.40 - (-13.60) = 10.2$ eV) and **12.09 eV** (level 1 → level 3: $-1.51 - (-13.60) = 12.09$ eV). It **can't take in 11.0 eV**: that would put the electron between levels 2 and 3, where there is no allowed orbit. An electron jumping outward must take in exactly the difference between two levels.

**MARKING SCHEME**

- ✓ 10.2 eV: level 1 to level 2.
- ✓ 12.09 eV: level 1 to level 3.
- ✓ 11.0 eV can't be taken in: it matches no difference between two levels.


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## 4 Where has the mass gone?

**ANSWER** A · 4

i. $17 \times 1.00728 = 17.124$; $18 \times 1.00866 = 18.156$; $17 \times 0.000549 = 0.0093$. Total = **35.289 u**.

ii. $35.289 - 34.969 = \mathbf{0.320\ u} = 0.320 \times 1.6605 \times 10^{-27} = \mathbf{5.31 \times 10^{-28}\ kg}$. It went into binding the nucleus.

iii. $0.0093 \div 34.969 \times 100 = \mathbf{0.027\%}$, which is why almost all the mass is taken to be in the nucleus.

**MARKING SCHEME**

✓ Total of the particles = 35.289 u.

✓ Missing mass 0.320 u = $5.31 \times 10^{-28}$ kg.

✓ It goes into binding the nucleus.

✓ Electrons are 0.027% of the mass.

## 5 A chain of nuclei

**ANSWER** A · 4

i.

| Atom | Z | N | A |
|---|---|---|---|
| carbon-14 | 6 | 8 | 14 |
| Q | 7 | 7 | 14 |
| R | 8 | 7 | 15 |
| S | 8 | 9 | 17 |

ii. Q is nitrogen-14, R is oxygen-15, S is oxygen-17.

iii. **None of the three:** Z (6 and 8), N (8 and 9) and A (14 and 17) are all different.

**MARKING SCHEME**

✓ Q: Z = 7, N = 7, A = 14.

✓ R: Z = 8, N = 7, A = 15, and S: Z = 8, N = 9, A = 17.

✓ Nitrogen-14, oxygen-15, oxygen-17.

✓ None of the three, because Z, N and A all differ.

## 6 Is the report possible?

**ANSWER** A · 4

i. Let M-21 be $x$ %, so M-22 is $(10.0 - x)$ %.

$(20.0 \times 90.0 + 21.0x + 22.0(10.0 - x)) \div 100 = 20.18$

$1800 + 21.0x + 220 - 22.0x = 2018$, so $2020 - x = 2018$ and $x = 2$.

**M-21 2.0%, M-22 8.0%.**

ii. An average can't be larger than the largest value going into it: the heaviest isotope is 22.0 u, so no mix of them can average 22.3.

**MARKING SCHEME**

✓ The equation, with the two percentages adding to 10.0.

✓ $x = 2$.

✓ M-21 2.0% and M-22 8.0%.

✓ An average can't be above the heaviest isotope's 22.0 u.



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## 7 Which law?

**ANSWER** U · 3

i. **A and B**: X and oxygen are in the same proportion, 3.0 : 2.0 and 6.0 : 4.0 are both 3 : 2. This fits the **law of constant proportions**.

ii. **The law of multiple proportions.** For a fixed 3.0 g of X, sample A has 2.0 g of oxygen and sample C has 4.0 g (twice its 1.5 g of X, twice its 2.0 g of oxygen). 2.0 : 4.0 = 1 : 2, a simple whole-number ratio.

**MARKING SCHEME**

- ✓ A and B, the same ratio 3 : 2.
- ✓ The law of constant proportions.
- ✓ C fits multiple proportions: for the same mass of X, the oxygen is in the ratio 1 : 2.

## 8 Which explanation fits the evidence?

**ANSWER** HA · 3

**Rizwan's.** An alpha particle is more than 7,000 times heavier than an electron, so an electron can't turn it round, any more than a ball can turn a truck round. And an electron is negative, so it attracts a positive alpha particle rather than pushing it away. Only a heavy positive center, the nucleus, repels it strongly enough to send it back, and that it happens so rarely shows the center is tiny.

**MARKING SCHEME**

- ✓ Rizwan's explanation.
- ✓ An alpha particle is over 7,000 times heavier than an electron, so an electron can't turn it back.
- ✓ An electron is negative, so it attracts rather than repels the positive alpha particle.

## 9 Comparing two beams

**ANSWER** A · 4

i. $e/m = 1.602 \times 10^{-19} \div (1.6726 \times 10^{-27}) =$ **$9.58 \times 10^{7}$ C/kg**.

ii. $1.76 \times 10^{11} \div (9.58 \times 10^{7}) =$ **about 1840 times**. The charges are equal in size, so this is how many times lighter the electron is than the proton, near the 1836 in the table.

iii. Canal rays are the atoms of the gas itself with electrons knocked off, so their mass depends on the gas. Cathode rays are electrons, the same in every atom.

**MARKING SCHEME**

- ✓ $e/m$ of a proton = $9.58 \times 10^{7}$ C/kg.
- ✓ About 1840 times.
- ✓ The charges are equal, so it shows the electron is about 1840 times lighter.
- ✓ Canal rays are the gas's own atoms without electrons; cathode rays are the same electrons from every atom.

## 10 Estimate

**ANSWER** A · 3

i. 0.000086 mm = $8.6 \times 10^{-5}$ mm = 86 nm, and $86 \div 0.29 \approx$ **300 atoms**.

ii. $(1/20{,}000)^3 = 1 \div (8 \times 10^{12}) =$ **about $1.25 \times 10^{-13}$**, about one part in 8 million million.

iii. 100 m ÷ 60,000 = 0.0017 m = **about 1.7 mm**.

**MARKING SCHEME**

- ✓ About 300 atoms.
- ✓ About $1 \div (8 \times 10^{12})$ of the volume.
- ✓ About 1.7 mm.



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## 11 Design it

(not marked)

**WHAT STUDENTS SHOULD FIND**

Roll many marbles along evenly spaced straight lines, at the same speed each time (the same push, from the same distance). If one big object is there, every marble aimed across its width is turned, and none gets through the middle. If a few small objects are there, most marbles come out straight and only a few are turned. Many marbles are needed, because small objects are easy to miss. Like Thomson's and Rutherford's atoms, the two arrangements differ inside, so you predict what each would do to the marbles and see which the results fit: most going straight points to mostly empty space.

## See it at Science Playground

Exhibits and plants at the center, Bhaktapur, that go with this unit. Book a class visit at science-playground.com/booking.

- **The Giant Periodic Table** (exhibit): The elements stand in order of atomic number: step along a row and each element has one proton more than the one before it.

| Marks by level | Knowledge | Understanding | Application | Higher ability | Total |
|---|---|---|---|---|---|
| **Marks** | 0 | 6 | 24 | 6 | **36** |