Unit 25 · Solids

ANSWER KEY · FOR TEACHERS

Full marks 36

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. valence
2. gap
3. hole
4. intrinsic
5. doping
6. donor
7. p-type
8. rectifier

K · 4

Each carries 0.5 mark.

2 Label the diagram

1. p-type
2. field
3. depletion layer
4. n-type

K · 2

Each carries 0.5 mark.

3 Multiple choice

i. **b.** 2.55 eV — A · 1

The photon carries the difference: $-0.85 - (-3.40) = 2.55$ eV.

ii. **c.** 13.6 eV — K · 1

The ground state is −13.6 eV; 13.6 eV lifts it to 0 eV, free.

iii. **b.** partly filled, or overlapping the band above — U · 1

Partly filled or overlapping bands give electrons empty levels just above their own, so they can carry a current.

iv. **c.** the depletion layer narrows and current flows once the supply is above the barrier potential — U · 1

Forward bias: p side to +; the supply works against the barrier, so the depletion layer narrows and current flows above about 0.7 V for silicon.

v. **c.** electrically neutral — U · 1

Each free electron came from a donor atom, left as a positive ion: the charges balance. The “n” names the majority carriers.

4 Very short answers

a. MARKING SCHEME — K · 1

✓ Any two of P, As, Sb.

b. MARKING SCHEME — K · 1

✓ Si 0.7 V, Ge 0.3 V.

c. MARKING SCHEME — U · 1

✓ Zero is the free electron; a bound one has less energy.

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5 Short answers

a. MARKING SCHEME U · 2

- ✓ A neighboring valence electron moves into the hole, leaving a new hole where it was: the hole moves the opposite way to the electrons.
- ✓ It moves as a positive charge would, towards the negative terminal, so it counts as a positive carrier.

b. MARKING SCHEME U · 2

- ✓ Photons with energy at least the band gap lift electrons from the valence band to the conduction band.
- ✓ Brighter light means more photons, so more free electrons and holes, and a lower resistance.

c. MARKING SCHEME A · 2

- ✓ The transformer changes the size of the alternating voltage (230 V down to a few volts).
- ✓ The rectifier (diodes) changes the alternating current into direct current.

6 Long answer

ANSWER U · 4

The n side has many free electrons and the p side many holes. Near the junction, free electrons diffuse across into the p side and fill holes there, and holes diffuse the other way. This leaves a thin layer with no free carriers, the depletion layer, holding fixed ions: positive donor ions on the n side and negative acceptor ions on the p side. Their charges make a field from n to p, a barrier potential (about 0.7 V in silicon) that stops more carriers crossing. Forward biased (p to +), the supply works against the barrier, the layer narrows and current flows; reverse biased, the supply adds to the barrier, the layer widens and almost no current flows.

MARKING SCHEME

- ✓ Electrons and holes diffuse across the junction and recombine.
- ✓ A layer with no free carriers is left, with fixed + ions on the n side and − ions on the p side.
- ✓ Their field is the barrier potential (Si about 0.7 V), stopping further crossing.
- ✓ Forward bias narrows the layer and conducts; reverse bias widens it: one way only.

7 Numerical problems

a. ANSWER A · 3

$E = 3.40 - 0.85 = 2.55$ eV $= 2.55 \times 1.6 \times 10^{-19} = 4.08 \times 10^{-19}$ J.

$\lambda = hc/E = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} \div 4.08 \times 10^{-19} =$ **4.9×10^{-7} m** (490 nm), **blue-green** visible light.

MARKING SCHEME

- ✓ $E = 2.55$ eV $= 4.08 \times 10^{-19}$ J.
- ✓ $\lambda = hc/E = 490$ nm.
- ✓ Visible (blue-green).

b. ANSWER A · 3

i. $5 \times 10^{28} \div 10^{6} =$ **5×10^{22} free electrons per m^3** (one from each arsenic atom).

ii. $5 \times 10^{22} \div 10^{16} =$ **5×10^{6} times** more. Arsenic is pentavalent: **n-type**.

MARKING SCHEME

- ✓ 5×10^{22} per m^3.
- ✓ 5×10^{6} times more.
- ✓ n-type.

c. ANSWER A · 3

$E = 13.6$ eV $= 13.6 \times 1.6 \times 10^{-19} = 2.18 \times 10^{-18}$ J.

$\lambda = hc/E = 6.63 \times 10^{-34} \times 3.0 \times 10^{8} \div 2.18 \times 10^{-18} =$ **9.1×10^{-8} m** (91 nm), in the ultraviolet. Any shorter wavelength ionizes it too, with energy to spare.

MARKING SCHEME

- ✓ $E = 13.6$ eV in joules.
- ✓ $\lambda = hc/E$.
- ✓ 91 nm (ultraviolet).

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8 Think

ANSWER HA · 3

Copper's resistance **falls**: it keeps its one free electron per atom, and as the atoms vibrate less they scatter the electrons less. Germanium's resistance **rises enormously**: fewer and fewer electrons have the energy to cross its band gap, so its free electrons and holes disappear, and near 0 K its valence band is full and its conduction band empty: it becomes an insulator.

MARKING SCHEME

- ✓ Copper: resistance falls, as the atoms vibrate less (its number of carriers stays the same).
- ✓ Germanium: fewer electrons cross the gap, so fewer carriers.
- ✓ Near 0 K germanium is an insulator.

9 Activity: Hot and cold resistance

(not marked)

WHAT STUDENTS SHOULD FIND

The thermistor's resistance falls sharply as it warms, by several times from iced to warm water: it is a semiconductor, and more electrons cross its gap. The copper's rises a little (a few percent over this range): no more carriers, only more scattering by the vibrating atoms.

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- **Plasma Ball** (exhibit): The gas glows because atoms excited by the discharge drop back between energy levels, giving out light of definite energies; another gas would glow another color.
- **Solar House Model** (exhibit): Each solar cell is a p–n junction: light frees electrons and holes, and the field across the depletion layer drives them apart, making the house's current.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	9	12	12	3	**36**

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