Unit 15 · Thermoelectric Effect

ANSWER KEY · FOR TEACHERS

Full marks 33

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. Seebeck effect → **d.** an e.m.f. set up in a loop of two different metals whose junctions are at different temperatures
2. Peltier effect → **a.** heat given out at one junction of a thermocouple and absorbed at the other when a current is passed
3. neutral temperature → **b.** the temperature of the hot junction at which the thermo e.m.f. is greatest
4. temperature of inversion → **c.** the temperature of the hot junction at which the thermo e.m.f. becomes zero and then reverses
5. thermopile → **f.** thermocouples joined in series to detect and measure heat radiation

Each carries 0.5 mark. **K · 2.5**

2 Label the graph

1. maximum
2. θn
3. θ (°C)
4. θi
5. reversed

Each carries 0.5 mark. **U · 2.5**

3 Multiple choice

i. **a.** from zinc to nickel through the cold junction **U · 1**

Through the cold junction the current flows from the metal earlier in the series to the later one: zinc to nickel (and so nickel to zinc through the hot junction).

ii. **c.** iron–nickel **U · 1**

The farther apart two metals are in the series (Sb, Fe, Zn, Ag, Au, Sn, Pb, Cu, Pt, Co, Ni, Bi), the larger the e.m.f.: iron and nickel are nine places apart; the others are neighbors.

iii. **c.** 480 °C **A · 1**

$\theta_n = (\theta_c + \theta_i)/2$, so $\theta_i = 2\theta_n - \theta_c = 500 - 20 = 480$ °C.

iv. **a.** 200 °C **A · 1**

$dE/d\theta = a + 2b\theta = 0$, so $\theta_n = -\dfrac{a}{2b} = \dfrac{30}{0.15} = 200$ °C. (400 °C comes from forgetting the 2: that is $-a/b$, the temperature of inversion.)

v. **b.** The Peltier heat is proportional to the current and changes sign when the current is reversed; Joule heat is proportional to its square and always heats. **K · 1**

The Peltier effect is reversible: reverse the current and a heated junction is cooled. Joule heating, I^2Rt, heats a wire whichever way the current flows.

4 Short answers

a. **MARKING SCHEME** **U · 2**

- ✓ The voltages along the two sides (or the contact potentials at the two junctions) are equal and opposite for one metal.
- ✓ They cancel, so there is no net e.m.f.: two different metals are needed.

Science Playground, Katunje, Bhaktapur
Book a class visit: https://science-playground.com/booking

b. MARKING SCHEME U · 2

- ✓ The slope $\alpha + \beta\theta$ does not contain the cold junction's temperature, so $\theta n = -\alpha/\beta$ is fixed.
- ✓ $\theta i = 2\theta n - \theta c$, so it changes with the cold junction's temperature.

c. MARKING SCHEME U · 2

- ✓ Sb and Bi are at the ends of the series: the largest e.m.f. per degree.
- ✓ Lamp black absorbs radiation well, so those junctions get warmer.

5 Long answer

ANSWER U · 4

The e.m.f. is greatest where $\frac{dE}{d\theta} = \alpha + \beta\theta = 0$, so $\theta_n = -\frac{\alpha}{\beta}$.

E is zero where $\theta(\alpha + \frac{1}{2}\beta\theta) = 0$; apart from $\theta = 0$, $\theta_i = -\frac{2\alpha}{\beta} = 2\theta_n$.

With the cold junction at θ_c, $E = \alpha(\theta - \theta_c) + \frac{1}{2}\beta(\theta^2 - \theta_c{}^2)$. Its slope is still $\alpha + \beta\theta$, so θ_n is the same.

Dividing E = 0 by $(\theta - \theta_c)$: $\alpha + \frac{1}{2}\beta(\theta + \theta_c) = 0$, so $\theta_i = -\frac{2\alpha}{\beta} - \theta_c = 2\theta_n - \theta_c$, that is $\theta_n = \frac{\theta_c + \theta_i}{2}$.

MARKING SCHEME

- ✓ $dE/d\theta = \alpha + \beta\theta = 0$ gives $\theta n = -\alpha/\beta$.
- ✓ E = 0 gives $\theta i = -2\alpha/\beta\ (= 2\theta n)$ for a cold junction at 0 °C.
- ✓ With the cold junction at θc, the slope is unchanged, so θn is the same.
- ✓ $\theta i = 2\theta n - \theta c$, so $\theta n = (\theta c + \theta i)/2$.

6 Numerical problems

a. ANSWER A · 4

i. $\theta_n = -\frac{\alpha}{\beta} = \frac{12}{0.05} = \mathbf{240}$ °C.

ii. $\theta_i = 2\theta_n = \mathbf{480}$ °C.

iii. At 240 °C: $E = 12 \times 240 - 0.025 \times 240^2 = 2880 - 1440 = 1440\ \mu V = \mathbf{1.44\ mV}$.

iv. At 100 °C: $E = 12 \times 100 - 0.025 \times 100^2 = 1200 - 250 = 950\ \mu V = \mathbf{0.95\ mV}$.

MARKING SCHEME

- ✓ $\theta n = 240$ °C.
- ✓ $\theta i = 480$ °C.
- ✓ The greatest e.m.f. 1.44 mV.
- ✓ 0.95 mV at 100 °C.

b. ANSWER A · 3

The difference is $24.6 \times 10^{-3} \div 41 \times 10^{-6} = \mathbf{600}$ °C, so the kiln is at 600 + 25 = **625** °C.

MARKING SCHEME

- ✓ $\Delta\theta = E \div (41\ \mu V/°C)$.
- ✓ $\Delta\theta = 600$ °C.
- ✓ The kiln at 625 °C (the cold junction's 25 °C added).

c. ANSWER A · 3

i. One thermocouple gives $0.10 \times 1.2 = 0.12$ mV; 50 in series give $50 \times 0.12 = \mathbf{6.0\ mV}$.

ii. $n = 9.0 \div 0.12 = \mathbf{75}$ thermocouples.

MARKING SCHEME

- ✓ 0.12 mV from each thermocouple.
- ✓ 6.0 mV in all (the e.m.f.s add in series).
- ✓ 75 thermocouples.

7 Think

ANSWER

Yes. $12\theta - 0.025\theta^2 = 950$ has two roots, $\theta = \mathbf{100}$ °C and $\theta = \mathbf{380}$ °C: the parabola rises to its maximum at 240 °C and falls again, so every e.m.f. below the maximum comes twice, once on each side of the neutral temperature. A thermocouple can be used as a thermometer only below its neutral

Science Playground, Katunje, Bhaktapur
Book a class visit: https://science-playground.com/booking

temperature (or with a second clue to say which side it is), so a pair of metals is chosen whose neutral temperature lies above the temperatures to be measured.

MARKING SCHEME

- ✓ The second temperature, 380 °C.
- ✓ Each e.m.f. below the maximum comes on both sides of the neutral temperature.
- ✓ So it must be used only below θn (choose metals whose θn is above the range).

8 Activity: Seeing the Seebeck effect (Activity 15.1)

(not marked)

WHAT STUDENTS SHOULD FIND

Zero in the room. A small reading appears as the junction heats up, a fraction of a millivolt at first and a few millivolts in the flame; out of the flame it falls back towards zero as the junction cools. In ice the reading has the opposite sign. The meter's terminals, at room temperature, act as the cold junction: the e.m.f. depends on the difference of temperature between the two junctions, and on its direction.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	3.5	14.5	12	3	**33**

Science Playground, Katunje, Bhaktapur
Book a class visit: https://science-playground.com/booking