Unit 12 · Rate of Heat Flow

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 25

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

Stefan's law needs the **absolute** temperature, in kelvin: T = 127 + 273 = 400 K.
$E = 5.67 \times 10^{-8} \times 400^4 =$ **1452 W/m²**, about a hundred times her answer.

MARKING SCHEME

- ✓ The mistake: the temperature in °C, not kelvin.
- ✓ T = 400 K.
- ✓ E = 1452 W/m².

2 Predict, then explain

ANSWER A · 4

i. **Nearer to 100 °C**: copper conducts so well that little temperature drop is needed across it; most of the drop is across the steel.

ii. In the steady state the same heat flows through both: $401A\frac{100-\theta}{l} = 50A\frac{\theta-0}{l}$, so $40\,100 - 401\theta = 50\theta$ and $\theta = 40\,100 \div 451 =$ **88.9 °C**.

MARKING SCHEME

- ✓ Nearer to 100 °C.
- ✓ The same rate of heat flow through both.
- ✓ $k_1(100-\theta) = k_2\theta$ set up.
- ✓ θ = 88.9 °C.

3 Read the data

ANSWER A · 4

i. **Yes**: the temperature falls by 15 °C every 10 cm, so the gradient is $15 \div 0.10 =$ **150 K/m**.

ii. $Q/t = kA \times \text{gradient} = 401 \times 4.0 \times 10^{-4} \times 150 =$ **24 W**.

iii. Heat would also escape from the sides, so less would reach each point farther along: the temperature would fall faster near the hot end and more slowly farther on, along a curve instead of a straight line.

MARKING SCHEME

- ✓ Uniform: 15 °C per 10 cm.
- ✓ Gradient 150 K/m.
- ✓ Q/t = 24 W.
- ✓ Unlagged, heat is lost from the sides, so the temperature falls along a curve.

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4 Show that

ANSWER A · 3

The same heat flows through each layer: $\frac{Q}{t} = \frac{k_1 A(\theta_1 - \theta)}{x} = \frac{k_2 A(\theta - \theta_2)}{x}$. So the temperature drops add: $\theta_1 - \theta_2 = \frac{Q}{t} \cdot \frac{x}{A}\left(\frac{1}{k_1} + \frac{1}{k_2}\right)$.

A single layer of thickness 2x needs $\theta_1 - \theta_2 = \frac{Q}{t} \cdot \frac{2x}{kA}$. Equal for the same flow when $\frac{2}{k} = \frac{1}{k_1} + \frac{1}{k_2}$, that is $k = \frac{2k_1 k_2}{k_1 + k_2}$.

MARKING SCHEME

- ✓ The same Q/t through each layer.
- ✓ The temperature drops add, with x/k for each layer.
- ✓ $2/k = 1/k_1 + 1/k_2$, so $k = 2k_1k_2/(k_1 + k_2)$.

5 Estimate it

ANSWER HA · 3

i. In balance, power absorbed = power radiated: $S\pi R^2 = 4\pi R^2 \sigma T^4$, so $T^4 = \frac{S}{4\sigma}$.

ii. $T = \left(\frac{1361}{4 \times 5.67 \times 10^{-8}}\right)^{1/4} = (6.0 \times 10^9)^{1/4} \approx$ **278 K**, about **5 °C**.

MARKING SCHEME

- ✓ $S\pi R^2 = 4\pi R^2 \sigma T^4$.
- ✓ T ≈ 278 K.
- ✓ About 5 °C.

6 Correct the misconceptions

ANSWER U · 3

1. Wool makes no heat: it traps still air, a poor conductor, which slows the loss of the body's own heat.
2. Both are at the same temperature (the air's); the metal feels colder because it is a good conductor and carries heat away from the hand faster.
3. A black body is the best emitter as well as the best absorber (a good absorber is a good emitter); it radiates σT^4 per square metre.

MARKING SCHEME

- ✓ Wool slows heat loss by trapping air; it makes no heat.
- ✓ Same temperature; the metal conducts heat from the hand faster.
- ✓ A black body is also the best emitter.

7 Think

ANSWER HA · 3

The **shiny** pot keeps the tea hot longer: a shiny surface is a poor emitter of radiation (a good reflector is a poor absorber and a poor emitter), so it loses less heat by radiation.

On a fire the **blackened** pot is better: a good absorber, it takes in more of the fire's radiation and the water heats faster.

The same property, being a good absorber and so a good emitter, helps in one case and hurts in the other.

MARKING SCHEME

- ✓ The shiny pot keeps tea hot longer: a poor emitter.
- ✓ The black pot heats faster on a fire: a good absorber.
- ✓ A good absorber is a good emitter, so the choice depends on the job.

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8 Make your own

ANSWER HA · 2

$Q/t = kA\Delta\theta/x \leq 100$, so $x \geq kA\Delta\theta/100 = 0.04 \times 10 \times 20 \div 100 = 0.08$ m. For example **x = 0.10 m** (10 cm): $Q/t = 0.04 \times 10 \times 20 \div 0.10 = 80$ W, under 100 W.

MARKING SCHEME

✓ $x \geq kA\Delta\theta/(Q/t) = 0.08$ m.

✓ A thickness chosen and checked.

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.

- **Which Feels Cooler?** (exhibit): Touch the wood, then the metal: at the same temperature the metal feels colder, because its far greater thermal conductivity draws heat from your skin faster.
- **Lava Lamp — Convection in Motion** (exhibit): Warm wax rises and cooled wax sinks in a steady loop: natural convection, heat carried upward by the moving fluid itself.
- **The Blackest Black** (exhibit): The center square is a hole into a dark box: light bounces round inside, absorbed a little each time, the way a cavity black body works.
- **The Inverse Square Law** (exhibit): Count the squares lit at one distance and at twice it: four times the area, a quarter as bright, as the Sun's power spreads over $4\pi r^2$.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	11	8	**25**

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