Unit 10 · Thermal Expansion

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. linear expansion
2. superficial expansion
3. cubical expansion
4. three
5. apparent expansion
6. real expansion
7. bimetallic strip
8. thermostat

Each carries 0.5 mark. **K · 4**

2 Label the diagram

1. rod
2. steam in
3. cell
4. steam out

Each carries 0.5 mark. **K · 2**

3 Multiple choice

i. **b.** K^{-1} **K · 1**

$\alpha = \Delta l/(l\,\Delta\theta)$: a length divided by a length and a temperature, so K^{-1} (the same as $^{\circ}C^{-1}$).

ii. **d.** $3.6 \times 10^{-5}\ K^{-1}$ **A · 1**

$\gamma = 3\alpha = 3.6 \times 10^{-5}\ K^{-1}$.

iii. **a.** its length **U · 1**

$F = YA\alpha\Delta\theta$: a longer rod would expand more, but its strain, $\Delta l/l = \alpha\Delta\theta$, is the same, so the force doesn't depend on its length.

iv. **b.** the glass is heated first and expands before the heat reaches the water **U · 1**

The heat reaches the flask first; its inside volume grows, so the level falls. Then the water warms and expands more than the glass, so the level rises.

v. **b.** platinum and soda glass have almost the same linear expansivity **U · 1**

Both have α of about $9 \times 10^{-6}\ K^{-1}$, so the wire and the glass shrink together as the seal cools, and the joint stays tight.

4 Short answers

a. **MARKING SCHEME** **U · 2**

- ✓ The steel girders expand in summer and contract in winter.
- ✓ Gaps or rollers let them move freely; held, they would set up large thermal stresses.

b. **MARKING SCHEME** **U · 2**

- ✓ The level shows the apparent expansion (real minus the vessel's).
- ✓ A liquid that expands much more than glass gives a clear rise.

c. **MARKING SCHEME** **A · 3**

- ✓ $\Delta l = l\alpha\Delta\theta$.
- ✓ $\Delta\theta = 60$ K put in.
- ✓ $\Delta l \approx 2.0$ cm.

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5 Long answer

ANSWER U · 4

At first its area is $A_1 = l_1^2$.
Each side grows: $l_2 = l_1(1 + \alpha\Delta\theta)$, so $A_2 = l_1^2(1 + \alpha\Delta\theta)^2 = A_1(1 + 2\alpha\Delta\theta + \alpha^2\Delta\theta^2)$.
α is very small (about 10^{-5} K^{-1}), so $\alpha^2\Delta\theta^2$ is far smaller still and can be left out: $A_2 = A_1(1 + 2\alpha\Delta\theta)$.
By definition $A_2 = A_1(1 + \beta\Delta\theta)$, so $\beta = \mathbf{2}\alpha$.

MARKING SCHEME

- ✓ $A_1 = l_1^2$ and $l_2 = l_1(1 + \alpha\Delta\theta)$.
- ✓ $A_2 = A_1(1 + \alpha\Delta\theta)^2$ expanded.
- ✓ $\alpha^2\Delta\theta^2$ neglected because α is very small.
- ✓ Compared with $A_2 = A_1(1 + \beta\Delta\theta)$: $\beta = 2\alpha$.

6 Numerical problems

a. **ANSWER** A · 4

The inner diameter must grow by $5.000 - 4.990 = 0.010$ cm. A hole grows as if it were filled with the metal, so $\Delta d = d\alpha\Delta\theta$.
$\Delta\theta = 0.010 \div (4.990 \times 1.9 \times 10^{-5}) = 105.5$ K.
$\theta = 20 + 105.5 \approx \mathbf{126}$ °C. (Once it cools, the ring grips the shaft tightly.)

MARKING SCHEME

- ✓ $\Delta d = 0.010$ cm needed.
- ✓ $\Delta d = d\alpha\Delta\theta$ (the hole grows like the metal).
- ✓ $\Delta\theta = 105.5$ K.
- ✓ $\theta \approx 126$ °C.

b. **ANSWER** A · 4

$\rho_2 = \dfrac{\rho_1}{1 + \gamma\Delta\theta} = \dfrac{13\,600}{1 + 1.82\times10^{-4} \times 50} = \dfrac{13\,600}{1.0091} = \mathbf{13\,477\ kg/m^3}$.
Volume of 1.00 kg: at 0 °C, $1 \div 13\,600 = \mathbf{7.353 \times 10^{-5}\ m^3}$ (73.53 cm^3); at 50 °C, $1 \div 13\,477 = \mathbf{7.420 \times 10^{-5}\ m^3}$ (74.20 cm^3).

MARKING SCHEME

- ✓ $\rho_2 = \rho_1/(1 + \gamma\Delta\theta)$.
- ✓ $\rho_2 = 13\,477$ kg/m^3.
- ✓ 73.53 cm^3 at 0 °C.
- ✓ 74.20 cm^3 at 50 °C.

7 Think

ANSWER HA · 3

The heat reaches the neck first, so the neck expands and its hole gets bigger, while the stopper inside is still cool. If it is done quickly, there is a moment when the neck has grown but the stopper hasn't, and the stopper comes loose. If the heating is slow, heat flows into the stopper too; it expands by about as much (the same glass), and nothing is gained.

MARKING SCHEME

- ✓ Heating expands the neck, and its hole grows.
- ✓ The stopper, still cool, hasn't expanded yet, so it loosens.
- ✓ Slowly, the stopper warms too and expands as much: so it must be quick.

8 Activity: A water thermometer

(not marked)

WHAT STUDENTS SHOULD FIND

The level rises when the bottle is warmed and falls when it is cooled: the water expands more than the glass. At the very start in warm water the level dips a little, because the glass warms and expands before the water does. The straw shows the apparent expansion of the water.

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- **Galileo Thermometer** (exhibit): As the liquid warms it expands, so its density falls and the bulbs sink one by one: a liquid's expansion read as a temperature.
- **Lava Lamp — Convection in Motion** (exhibit): Heated at the bottom, the wax expands and its density falls below the liquid's, so it rises; cooled at the top, it contracts and sinks again.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	7	11	12	3	**33**

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