Unit 5 · Second Law of Thermodynamics

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 30

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

The temperatures must be **absolute**, in kelvin. $T_1 = 227 + 273 = 500$ K and $T_2 = 27 + 273 = 300$ K, so $\eta = 1 - \frac{300}{500} = \mathbf{40\%}$.

MARKING SCHEME

- ✓ The mistake: temperatures in °C instead of kelvin.
- ✓ $T_1 = 500$ K, $T_2 = 300$ K.
- ✓ $\eta = 40\%$.

2 A real setting

ANSWER A · 4

i. $\eta_{\text{Carnot}} = 1 - \frac{310}{820} = \mathbf{62\%}$.

ii. $Q_1 = W/\eta = 500 \div 0.38 = \mathbf{1316\ MW}$ (1.3×10^9 J each second).

iii. $Q_2 = Q_1 - W = 1316 - 500 = \mathbf{816\ MW}$, more than the electrical power itself.

MARKING SCHEME

- ✓ Carnot limit 62%.
- ✓ $Q_1 = W/\eta$.
- ✓ $Q_1 = 1316$ MW.
- ✓ $Q_2 = 816$ MW.

3 Check the claim

ANSWER A · 3

The best possible: $T_2 = 268$ K, $T_1 = 303$ K, $\beta_{\max} = \frac{T_2}{T_1 - T_2} = \frac{268}{35} = \mathbf{7.7}$.

No refrigerator between these temperatures can beat a reversible one, so a coefficient of 12 is **impossible**: the claim breaks the second law.

MARKING SCHEME

- ✓ Temperatures in kelvin: 268 K and 303 K.
- ✓ The best coefficient is 7.7.
- ✓ 12 is more than the ideal, so the claim is false.

4 Show that

ANSWER HA · 3

The efficiencies are $1 - \frac{T}{T_1}$ and $1 - \frac{T_2}{T}$. They are equal when $\frac{T}{T_1} = \frac{T_2}{T}$, that is $T^2 = T_1 T_2$, so $T = \sqrt{T_1 T_2}$.

For 800 K and 320 K: $T = \sqrt{800 \times 320} = \mathbf{506\ K}$.

MARKING SCHEME

- ✓ Each efficiency written as 1 − (cold)/(hot).
- ✓ Equal when $T^2 = T_1 T_2$.
- ✓ T = 506 K.

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5 Predict, then explain

ANSWER HA · 3

i. The **heat pump**. The heater turns 1 kJ into 1 kJ of heat. The heat pump gives the room the heat it takes from outside plus the work: $Q_1 = Q_2 + W$, always more than W.

ii. For an ideal one, $\frac{Q_1}{W} = \frac{T_1}{T_1 - T_2} = \frac{293}{15} = 19.5$: up to **about 20 kJ** of heat for 1 kJ of electricity.

MARKING SCHEME

- ✓ The heat pump gives more.
- ✓ $Q_1 = Q_2 + W$, more than W.
- ✓ Up to $293/15 \approx 20$ kJ for 1 kJ.

6 Read the data

ANSWER A · 3

i. **No**: from 42.6% to 56.5%, a rise of about a third. Each further rise in r gains less.

ii. $1 - \frac{1}{8^{\gamma-1}} = 0.565$, so $8^{\gamma-1} = \frac{1}{0.435} = 2.30$, and $\gamma - 1 = \frac{\log 2.30}{\log 8} = 0.40$: γ **= 1.4**, air.

MARKING SCHEME

- ✓ No: the gain is about a third, and it shrinks as r grows.
- ✓ $8^{\gamma-1} = 1/0.435$.
- ✓ $\gamma = 1.4$.

7 What if?

ANSWER A · 3

Diesel: $1 - \frac{1}{16^{0.4}} \times \frac{2.5^{1.4} - 1}{1.4 \times 1.5}$ = **59%**. Petrol at r = 16: $1 - \frac{1}{16^{0.4}}$ = **67%**, higher.

But a petrol–air mixture squeezed that hard gets hot enough to catch fire by itself before the spark (knocking), so petrol engines are kept to 8–12, below a diesel's 14–25.

MARKING SCHEME

- ✓ Diesel 59%.
- ✓ Petrol at r = 16: 67%.
- ✓ Knocking keeps petrol engines' compression ratios low.

8 Correct the misconceptions

ANSWER U · 3

1. No engine working in a cycle can turn all its heat into work, however well made: it must give heat to a colder sink (Kelvin–Planck). It isn't only friction.
2. The efficiency of a reversible engine depends only on the two temperatures, $1 - T_2/T_1$, not on its working substance: steam and air give the same.
3. A refrigerator doesn't destroy heat; it moves it, with work, from the inside to the room, giving out $Q_1 = Q_2 + W$ at the back.

MARKING SCHEME

- ✓ No engine can be 100% efficient: it needs a sink.
- ✓ Carnot efficiency doesn't depend on the working substance.
- ✓ A refrigerator moves heat out to the room; it doesn't destroy it.

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9 Think

ANSWER HA · 3

$\Delta S = -2500/480 + 2500/240 = -5.21 + 10.42 =$ **+5.2 J/K**.
A Carnot engine: $W = 2500 \times (1 - 240/480) =$ **1250 J**.
Letting the heat flow straight across wasted the chance of that 1250 J of work: energy is not lost, but it ends up less able to do work. The rise in entropy measures that loss (240 K × 5.21 J/K = 1250 J).

MARKING SCHEME

- ✓ Total entropy rises by 5.2 J/K.
- ✓ A Carnot engine could have done 1250 J of work.
- ✓ The energy is degraded: it is still there, but less able to do work.

10 Make your own

ANSWER HA · 2

$T_2/T_1 = 1 - 0.25 = 0.75$, and $T_2 = 288$ K, so $T_1 = 288 \div 0.75 =$ **384 K** (111 °C). For $W = 900$ J, $Q_1 = W/\eta$ = **3600 J**.

MARKING SCHEME

- ✓ $T_1 = 288 \div 0.75 = 384$ K.
- ✓ $Q_1 = 3600$ J.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	13	11	**30**

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