Grade 12 Physics, Explained

Unit 5 · Second Law of Thermodynamics

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. heat engine
2. thermal efficiency
3. Carnot's engine
4. refrigerator
5. coefficient of performance
6. Otto cycle
7. compression ratio
8. entropy

K · 4

Each carries 0.5 mark.

2 Label the diagram

1. evaporator
2. valve
3. condenser
4. compressor

K · 2

Each carries 0.5 mark.

3 Multiple choice

i. **b.** no engine working in a cycle can turn all the heat it takes in into work — K · 1

Every heat engine must give out some heat to a colder sink: no engine can be 100% efficient.

ii. **b.** 33% — A · 1

$\eta = 1 - T_2/T_1 = 1 - 300/450 = 1/3 \approx 33\%$.

iii. **c.** 9 — A · 1

$\beta = T_2/(T_1 - T_2) = 270/(300 - 270) = 9$.

iv. **b.** when its compression ratio is raised — U · 1

$\eta = 1 - 1/r^{\gamma - 1}$ depends only on the compression ratio r (and γ): the larger r, the higher η.

v. **c.** the total entropy rises — U · 1

The tea loses heat at a higher temperature than the room gains it, so the room's gain in entropy is larger than the tea's loss: the total rises, as in every natural process.

4 Short answers

a. MARKING SCHEME — U · 2

- ✓ Air alone is compressed adiabatically to a high compression ratio and becomes very hot.
- ✓ The fuel sprayed in catches fire by itself in the hot air.

b. MARKING SCHEME — K · 2

- ✓ Any one, e.g. a petrol engine draws in an air–petrol mixture and lights it with a spark plug; a diesel engine draws in air only and the fuel catches fire in the hot compressed air.
- ✓ Any second, e.g. a petrol engine's compression ratio is lower (8 to 12, limited by knocking) than a diesel's (14 to 25), so the diesel engine is more efficient; in the petrol engine heat is added at constant volume, in the diesel at constant pressure.

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c. MARKING SCHEME A · 3

✓ $W = Q_2/\beta = 100$ J.
✓ $Q_1 = 1000$ J.
✓ A sensible reason a real one needs more work.

5 Long answer

ANSWER U · 4

1. **Isothermal expansion (AB)**: on the source at T_1, the gas expands slowly; it takes in heat Q_1 and does an equal amount of work; its temperature stays T_1.
2. **Adiabatic expansion (BC)**: on the insulating stand, the gas keeps expanding with no heat in; it does work out of its internal energy and cools from T_1 to T_2.
3. **Isothermal compression (CD)**: on the sink at T_2, the gas is compressed slowly; work is done on it and it gives out an equal heat Q_2 to the sink; its temperature stays T_2.
4. **Adiabatic compression (DA)**: on the insulating stand, the gas is compressed with no heat out; the work done on it raises its temperature from T_2 back to T_1.

MARKING SCHEME

✓ Isothermal expansion on the source, taking in Q_1 at T_1.
✓ Adiabatic expansion on the stand, cooling from T_1 to T_2.
✓ Isothermal compression on the sink, giving out Q_2 at T_2.
✓ Adiabatic compression on the stand, warming back to T_1.

6 Numerical problems

a. ANSWER A · 4

i. $\eta = 1 - \dfrac{Q_2}{Q_1} = 1 - \dfrac{1500}{2400} = 0.375 = \mathbf{37.5\%}$.

ii. $T_1 = 800$ K, $T_2 = 300$ K: $\eta_{\text{Carnot}} = 1 - \dfrac{300}{800} = 0.625 = \mathbf{62.5\%}$.

iii. $W = 0.625 \times 2400 = \mathbf{1500\ J}$ (it would give out only 900 J to the sink).

MARKING SCHEME

✓ $\eta = 1 - Q_2/Q_1 = 37.5\%$.
✓ Temperatures in kelvin: 800 K and 300 K.
✓ Carnot efficiency 62.5%.
✓ W = 1500 J.

b. ANSWER A · 4

Heat taken in: $Q = mL = 0.50 \times 334\,000 = 167\,000$ J.

i. Ice, at 273 K: $\Delta S = \dfrac{167\,000}{273} = \mathbf{+612\ J/K}$.

ii. Room, at 293 K: $\Delta S = -\dfrac{167\,000}{293} = \mathbf{-570\ J/K}$.

iii. Total: $612 - 570 = \mathbf{+42\ J/K}$. The total entropy rises, so the melting happens by itself: it is natural.

MARKING SCHEME

✓ Q = mL = 167 000 J.
✓ ΔS of the ice = +612 J/K.
✓ ΔS of the room = −570 J/K.
✓ Total +42 J/K, a rise, so the process is natural.

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7 Think

ANSWER HA · 3

No, it would get warmer. With the door open, the refrigerator takes heat Q_2 from the kitchen air in front and gives out $Q_1 = Q_2 + W$ at the back, into the same kitchen. Each cycle adds the work W (the electrical energy) to the kitchen as heat, so the room warms.

MARKING SCHEME

- ✓ The heat taken in front is given back at the back into the same room.
- ✓ It gives out more heat than it takes in: $Q_1 = Q_2 + W$.
- ✓ So the kitchen warms by the work done.

8 Activity: Watch heat flow downhill

(not marked)

WHAT STUDENTS SHOULD FIND

The hot water cools and the cold water warms until they reach nearly the same temperature; then nothing more changes. Heat always flows from the hot to the cold by itself, never back: the Clausius statement. The total entropy rose, since the heat left the hot water at a higher temperature than it entered the cold.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	9	8	13	3	**33**

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