A-Level Physics

Second Law and Engines

Mark Scheme

Time available: 62 minutes
Marks available: 35 marks

1. (a) The efficiency is 50% when the kelvin temperature of the hot source is twice the kelvin temperature of the cold sink. ✓

1

(b) Identifies $Q_H = 3 \times W$ and $Q_C = Q_H - W$ ✓

In reverse $COP_{ref} = QC / W$

Leading to $COP_{ref} = 2$ ✓

MP1 can be awarded for

$Q_H - Q_C = 0.33Q_H$ or $Q_C = 0.67Q_H$

Give credit for substituting numbers in equations eg

$W = 1$ $Q_H = 3$, $Q = 2$

OR $W = 33$ $Q_H = 100$, $Q_C = 67$

Accept working shown on a diagram

Accept working using temperatures T_H T_C with numbers substituted eg $T_H = 300$ (K), $T_C = 200$ (K)

No credit for simply quoting formulae from Formulae Booklet.

2

[3]

2. (a) (For 2nd law of thermodynamics to apply...)
Engine must operate between hot and cold reservoirs ✓
And must reject some energy to cold reservoir ✓
(Meaning W cannot equal Q_H)

accept hot and cold spaces / hot source and cold sink / high and low temperatures

Accept for 2nd mark:

For 100% efficiency T_C would have to be 0 K

(which is impossible)

2

(b) 175 ºC = 448 K and 30 ºC = 303 K and ✓1

$\eta = \frac{T_H - T_C}{T_H}$ ✓1

$= \frac{448 - 303}{448} = 0.32$ ✓2

$(\eta = \frac{W}{Q_C + W}$ so $Q_C = \frac{W}{\eta} - W)$

$Q_C = \frac{2.9}{0.32} - 2.9 = 6.2$ MW ✓3

6.2 MW < 6.4 MW so claim is not true ✓4

Alternatives for 3rd and 4th marks:

For QC =6.4 MW, $\eta = \frac{2.9}{2.9+6.4} = 0.31$ ✓3

Actual $\eta > 0.31$ so QC has to be < 6.4 MW

so claim not true ✓4

1st mark for converting to K and giving thermal efficiency equation

2nd mark for calculating efficiency

3rd mark for another relevant calculation

4th mark for a comparison leading to a conclusion regarding claim. This is not an independent mark.

e.g. 4th mark: claim is not true (based on ideal engine) because 6.2 MW < 6.4 MW ✓4

OR

input power = $\frac{2.9}{0.32}$ = 9.1 MW

input power needed for company claim = 2.9 + 6.4 = 9.3 MW ✓3

9.1 < 9.3 so claim not true ✓4

OR accept: claim is true; for real engine η will be (considerably) less, so energy available for greenhouse heating will be/is likely to be higher than 6.4 MW

If temperatures <u>not</u> changed to K condone giving ECF for marks ✓3 and ✓4 :

$\eta = \frac{175 - 30}{175} = 0.83$ = *0.83*

$Q_C = \frac{2.9}{0.83} - 2.9 = 0.6$ *MW ✓3*

0.6 < 6.4 so claim not true ✓4

4

[6]

3. (a) η = (1450-310) / 1450 = 0.79 / 79%✓ 1

(b) Claim 1: input power = $55.5 \times 10^6 \times 5.00 \times 10^{-3}$ = 278 kW ✓
actual claimed efficiency = 210 / 278 = 0.76 / 76% ✓

1

claim not justified because actual efficiency too close to max theoretical. ✓

1

OR claim would be justified if engine ran at max efficiency (giving 218 KW electrical power) ✓

1

Claim 2: 278 kW – 210 kW = 68 kW ✓
Judgement: claim justified because 55 kW < 68 kW ✓ (and allows for some unwanted energy loss to surroundings)

1

OR for claim 2:
any efficiency lower than 79% will give more than 68 kW of heating (WTTE) so claim justified✓

1

[6]

4. (a) T_H = 273 + 540 = 813 K
T_C = 273 + 25 = 298 K ✓
η_{max} = (813 . 298) / 813 = 0.633 or 63.3 % ✓

Both temperatures correct for 1st mark.
No CE for incorrect temperatures
If °C used η_{max} = 95.4%

2

(b) input power = $\dfrac{\text{output power}}{\eta_{max}}$

Give CE from (a) unless η_{max} > 1

= $\dfrac{48.0}{0.633}$ = 75.8 MW ✓

If η_{max} = 0.95 used, input power = 50 MW

1

(c) • Heat exchanger will not convert all (internal) energy of salts to (internal) energy of water / steam

WTTE

E.g. turbine to surrounding air

• (Unwanted) heat transfer losses **from** … … **to** … … .

Do not accept bland statements e.g. 'heat loss to surroundings', 'friction' / 'friction in steam turbine'

• Friction … in bearings of all machinery / in bearings of turbine generator / between moving parts / between moving surfaces / from viscosity of lubricants

• Power needed to drive auxiliary equipment e.g. pumps, motors

• Turbine cycle will not give max theoretical efficiency

Do not allow: turbine generator is not 100% efficient

any 2 ✓✓

2

[5]

5. (a) (i) $3.2 \times 780 = 2500$ W ✓

1

(ii) $2500 - Q_{out} = 780$

$Q_{out} = 1720$ W ✓

or $3.2 = \dfrac{Q_{in}}{Q_{in} - Q_{out}} = \dfrac{2500}{2500 - Q_{out}}$

giving $Q_{out} = 1720$ W ✓

1

(b) • heat pump does deliver more energy than is input as work on the system but there must also be energy input from cold space ✓

• obeys conservation of energy because work done plus energy from cold space (or equivalent, eg ground) equals energy by heat transfer to hot space (or equivalent) ✓

• obeys second law because (reversed heat engine) operates between hot and cold spaces

[accept 'source' and 'sink'] ✓

• work done on the system requires energy transfer (from a heat engine elsewhere) so overall result is spreading out of energy [owtte] ✓

max 3

[5]

6.

(a) (i) $\eta_{max} = \frac{T_H - T_C}{T_H}$ **(1)**

$= \frac{913 - 293}{913}$ = 68% **(1)**

(ii) 0.68 × 200 kW = 136 kW **(1)**

(3)

(b) (i) P_{out} = 0.34 × 200 = 68 kW **(1)**

(ii) power to reservoir = 200 – 68= 132 kW **(1)**

(iii) 0.52 × 132 = 68.6 kW **(1)**

(iv) $\eta = \frac{\text{total power out}}{\text{power in}} = \frac{68.6 + 68}{200}$ = 69% **(1)**

(4)

(c) theoretical efficiencies of single and two stage engines *exactly* same*
efficiency of two stage engine cannot be greater*
apparent difference due to rounding errors in calculations*
* any two **(1) (1)**
<u>hence</u> designer's argument is false **(1)**

(3)

[10]