M1. (a) pV = constant for any two points online AB **(1)**
two points chosen and constant calculated **(1)**
(e.g. at A, $pV = 1.0 \times 10^5 \times 1.0 \times 10^{-3} = 100$ (J)
at B, $pV = 5.0 \times 10^5 \times 0.2 \times 10^{-3} = 100$ (J))

2

(b) A → B and C → A **(1)**

1

(c) $W = p\Delta V$
$= 5.0 \times 10^5 \times (1.0 - 0.2) \times 10^{-3} = 400$ (J) **(1)**

1

(d) (i) C **(1)**

1

(ii) $pV = nRT$ **(1)**

$5.0 \times 10^5 \times 1.0 \times 10^{-3} = 6.9 \times 10^{-2} \times 8.3 \times T$ **(1)**

T=870K (872K) **(1)**

(allow C.E. if wrong point in (i))

4

[9]

M2. (a) $T_H = 273 + 820 = 1093$ (K), $T_C = 273 + 77 = 350$ (K) **(1)**

efficiency = $\frac{T_H - T_C}{T_H} = \frac{1093 - 350}{1093}$ = 0.68 or 68% **(1)**

2

(b) rotational speed of output shaft = $\frac{1800}{2 \times 60}$ = 15 rev s^{-1} **(1)**

(work output each cycle = 380 J, 2 rev ≡ 1 cycle in a 4 stroke engine)

indicated power = 15 × 190 = 5.7 kW **(1)**

2

(c) power lost (= indicated power –actual power) = 5.7 – 4.7 = 1.0 kW **(1)**
(allow C.E. for incorrect value from (b))

1

(d) energy supplied per sec (= fuel flow rate x calorific value)

$= \frac{2.1 \times 10^{-2}}{60} \times 45 \times 10^6$ = 16 kW (15.8 kW) **(1)**

1

(e) efficiency = $\frac{\text{net power output}}{\text{power input}} = \frac{4.7}{16}$ = 0.29 or 29 %

$\frac{4.7}{15.8}$ = 0.30 or 30%

(allow C.E. for value from (d))

1

[7]

M3. (a) work per cycle = area enclosed = $6 \times 10^5 \times 4.5 \times 10^{-3}$ = 2.7 (kJ) **(1)**

power = work output per sec = $\frac{2700}{0.20}$ = 13.5 kW **(1)**

(allow C.E. for incorrect work per cycle)

2

(b) modified engine uses less steam per cycle **(1)**
so lower energy input per cycle **(1)**
input energy per cycle ≈ ⅓ of that in unmodified cycle **(1)**
work output per cycle is less than for unmodified cycle **(1)**
work output per cycle > ½ of that in unmodified cycle **(1)**
hence greater efficiency **(1)**

max 4
QWC 2

[6]

M4. (a) (use of pV^γ = *constant* gives)
$1.01 \times 10^5 \times (4.25 \times 10^{-4})^{1.4} = 1.70 \times 10^5 \times V^{1.4}$ **(1)**
V calculated correctly (= 2.93×10^{-4})
or substitution to show equal pV^γ **(1)**

2

(b) $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ **(1)**
T_1 = 273 + 23 = 296 (K) **(1)**

T_2 = =343 K (70 °C) **(1)**

3

(c) slow compression is isothermal (temperature does not increase) **(1)**
greater change in volume needed to rise to same final pressure **(1)**
(or correct pV sketches showing adiabatic and isothermal processes)
hence less **(1)** **(1)**

3

[8]

M5. (a) P_{in} (= fuel flow rate × calorific value)

$= 4.45 \times 10^{-4} \times 42.9 \times 10^{6} = 19$ kW **(1)** (19.1 kW)

1

(b) (i) work done = area enclosed by loop **(1)**
suitable method of finding area (e.g. counting squares) **(1)**
correct scaling factor used **(1)** (to give answer of ≈ 350 J)

(ii) 2400 rev min^{-1} = 40 rev s^{-1} and each two revolutions produce 350 J **(1)**

$$P_{ind} = \frac{350}{2} \times 40 = 7.0 \text{ kW}$$ **(1)**

5

(c) (i) power used overcoming friction <u>inside the cylinder</u>
power used in driving valve gear, oil pump, cooling etc
power used in induction and exhaust strokes any two **(1)** **(1)**

(ii) efficiency $= \frac{6.3(\text{kW})}{19.1(\text{kW})} = 33\%$ (kW) **(1)**

(allow C.E. for value of P_{in} in (a))

3

QWC 2

[9]

M6. (i) $V = 80 \times 10^{-3} \times 1.77 \times 10^{-4}$ **(1)** $(= 1.416 \times 10^{-5})$

$$n\left(= \frac{pV}{RT}\right) = \frac{1.03 \times 10^{5} \times 1.416 \times 10^{-5}}{8.31 \times 291} = 6.0(3) \times 10^{-4} \text{ (moles)}$$ **(1)**

(allow C.E. for value of V)

(ii) $P_2 = P_1\left(\frac{V_1}{V_2}\right)^{\gamma}$ **(1)**

$= 1.03 \times 10^5 \times \left(\frac{80}{2.0}\right)^{1.4} = 1.80 \times 10^7$ Pa **(1)**

(iii) $T_2 = \frac{p_2 V_2}{nR}$ or $T_2 = \frac{p_2 V_2 T_1}{P_1 V_1}$ **(1)**

$T_2 = \frac{1.80 \times 10^7 \times 2.0 \times 10^{-3} \times 1.77 \times 10^{-4}}{6.03 \times 10^{-4} \times 8.31} = 1.3 \times 10^3$ K **(1)** (1.27 × 10^3 K)

(allow C.E. for value of p_2 or n)

[6]

M7. (a) **remove heat** from the gas **(1)**
correct reference to equation (e.g. Δ*Q* negative, *W* zero, then Δ*U* must be negative so *U* decreases) **(1)**

allow gas to do work **(1)**
correct reference to equation (e.g. *W* positive, Δ*Q* zero, then Δ*U* must be negative so *U* decreases) **(1)**

max 3
QWC 1

(b) (i) *W* (= *p*d*V*) = 1.0 × 10^5 × 10 = 1.0 × 10^6 J **(1)** (1.0 MJ)

(ii) –4.9 (MJ) = Δ*U* – 1 (MJ) **(1)**
Δ*U* = (–)3.9 MJ **(1)**

(iii) graph to show: straight line between (20, 1.0) and (10, 1.0) **(1)**
direction showing decreasing volume **(1)**

5

[8]

M8. (a) 1.3×10^5 Pa **(1)**

1

(b) (i) work done = area enclosed by loop **(1)**
suitable method used to find area (e.g. counting squares) **(1)**
correct scaling factor used **(1)**
(work done) = 0.11 J **(1)** (accept 0.08 to 0.14 J)

(ii) 360 rev min^{-1} $\left(= \frac{360}{30}\right)$ = 6 cycles sec^{-1} **(1)**

power (= 2 cylinders × 0.11 J per cylinder × 6 cycles sec^{-1})
= 2 × 6 × 0.11 = 1.3 W **(1)** (0.96 to 1.56 W)

6

(c) friction between sliding surfaces
air resistance in tubing
heat generated by fast compression lost to surroundings (any one) **(1)**

1

[8]

M9. (a) (i) work done = area enclosed by curve ABCD = 20 kJ (± 2 kJ) **(1)**
satisfactory method of finding the area **(1)**

(ii) power = 20 kJ per cycle × 3 cycles per sec = 60 kJ (± 6 kJ) **(1)**

(iii) input power = fuel flow rate × calorific value

$= 2.4 \times 10^{-3} \times 34 \times 10^6 = 820$ kW **(1)** (816 kW)

efficiency = $\frac{P_{out}}{P_{in}} = \frac{60 \times 10^3}{816 \times 10^3} \times 100 = 7.3(5)\%$ **(1)**
(use of input power = 820 gives 7.3%)

(allow C.E. for values of output power and input power)

5

(b) modified engine:
same steam requirement **(1)**
less fuel supplied because of recycled heat **(1)**
greater work output per cycle (because loop larger) **(1)**
same speed, therefore greater power output **(1)**
greater efficiency as P_{out} greater, P_{in} less **(1)**

max 3
QWC 1

[8]

M10. (a) P_{in}(= calorific value × fuel flow rate)

$= \frac{36 \times 10^6 \times 9.6}{3600}$ **(1)** **(1)** (for conversion to 3600 s) (= 96 kW)

2

(b) $\eta \left(= \frac{T_H - T_C}{T_H} \right) = \frac{1400 - 360}{1400}$ = 0.74 or 74% **(1)**

1

(c) η claimed in (a) = $\frac{80(\text{kW})}{100(\text{kW})}$ = 0.80 or 80% **(1)**

[or $\frac{80(\text{kW})}{96(\text{kW})}$ = 0.83 or 83%]

which is > 74%, so claim 1 is unjustified **(1)**

heat rejected from engine = $P_{in} - P_{out}$ **(1)**

real mechanical P_{out} must be < 0.74 × 100 i.e. < 74 kW **(1)**

so claim 2 is justified as $P_{in} - P_{out}$ > 20 kW **(1)**

[alternative for (c):

maximum *P*out = 71 kW (0.74 × 96) or 74 kW (0.74 × 100) **(1)**

which is < 80 kW, so claim 1 is unjustified **(1)**

heat rejected from engine is 25 kW (96 – 71) or 26 kW (100 – 74) **(1)**

actual wasted power must be > 25 kW **(1)**

claim 2 is justified as 25 kW > 20 kW **(1)**]

Max 4
QWC 1

[7]

M11. (a) $p_1V_1 = 7.8 \times 10^5 \times 1.6 \times 10^{-4} = 125$ (Pa m^3)

$p_2V_2 = 1.9 \times 10^5 \times 6.6 \times 10^{-4} = 125$ (Pa m^3) **(1)**

suitably correct comment **(1)**

2

(b) (i) adiabatic → no heat enters (or leaves) gas,
rapid expansion so no time for heat transfer **(1)**

(ii) $(p_1V_1^{\gamma} = p_2V_2^{\gamma})$ gives $V_2 = \left(\frac{p_1V_1^{\gamma}}{p_2}\right)^{1/\gamma}$

$= \left(\frac{1.9\times10^{5}\times(6.6\times10^{-4})^{1.4}}{9.8\times10^{4}}\right)^{1/1.4}$ **(1)** = 1.1(0) × 10^{-3} m^3 **(1)**

3

[5]

M12. (a) $p_1V_1^{\gamma} = p_2V_2^{\gamma}$, two points chosen on section BC,
e.g. at B and C, $p_1V_1^{\gamma} = 29$ and $p_2V_2^{\gamma} = 29$ **(1)**

1

(b) (use of $pV = nRT$ gives) $n = \left(\frac{pV}{RT}\right) = \frac{2.0\times10^{6}\times3.5\times10^{-4}}{8.3\times350}$ **(1)**
= 0.24(1) (moles) **(1)**

2

(c) (use of $pV = nRT$, gives) $T = \left(\frac{pV}{nR}\right) = \frac{0.9\times10^{6}\times6.2\times10^{-4}}{0.24\times8.3}$
= 280 K **(1)** (7 °C)
(allow C.E. for value of *n* from (b))

1

(d) work done = area under curve A → C = 1050 ± 100 J **(1)**
satisfactory method of finding the area e.g. counting squares **(1)**

2

[6]

M13. (a) (i) work done (per kg) = area enclosed (by loop) **(1)**
suitable method of finding area (e.g. counting squares) **(1)**
correct scaling factor **(1)**
(to give answer ≈ 500 kJ)

(ii) *P* (= work done per kg x fuel flow rate)
= 500 (kJ) × 9.9 (kgs^{1}) = 5000kW **(1)**
(4950kW)

(iii) (output power = indicated power – friction power)
P_{out} = 4950 – 430 = 45(20) kW **(1)**
(use of *P* = 5000 gives P_{out} = 45(70)kW)

(allow C.E. for values of P in (ii))

5

(b) (i) P_{in} (= fuel flow rate × calorific value)

$= 0.30 \times 44 \times 10^6 = 13(.2) \times 10^6$W **(1)**

efficiency = $\frac{4520 \times 10^3}{13.2 \times 10^6} = 34\%$ **(1)**

(allow C.E. for value of P_{out} in (a) (iii) and P_{in} in (b) (i))

2

[7]

M14. (a) use of = $P_2V_2^{\psi}$ **(1)**

(gives $p_2 = p_1 \left(\frac{V_1}{V_2}\right)^{\gamma}$)

$p_2 = (1.0 \times 10^5) \left(\frac{1.2 \times 10^{-5}}{3.1 \times 10^{-7}}\right)^{1.4}$ **(1)**

$(=1.6(7) \times 10^7$Pa)

2

(b) (i) $n = \frac{p_1V_1}{RT_1}$ **(1)**

$= \frac{1.0 \times 10^5 \times 1.2 \times 10^{-5}}{8.31 \times 290} = 5.0 \times 10^{-4}$ mol **(1)**

$(4.98 \times 10^{-4}$ mol)

(ii) (use of $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ or use of n, p_2 and V_2 in $pV = nRT$ gives)

$T_2 = \frac{(1.7 \times 10^7) \times (3.1 \times 10^{-7}) \times 290}{(1.0 \times 10^5) \times (1.2 \times 10^{-5})}$ **(1)**

= 1300K **(1)**
(1247 K)

$\left[or T = \frac{(1.7 \times 10^7) \times (3.1 \times 10^{-7})}{5.0 \times 10^{-4} \times 8.31} \right]$

4

(c) $\Delta Q = \Delta U + W$ with symbols explained **(1)**

if plunger pushed in slowly, sufficient time for heat transfer **(1)**
most of work done (W) goes to heat transfer from tube
or into metal plug **(1)**

any increase in ΔU will be zero or small **(1)**
[or $\Delta U = 0$]
relates ΔU to temperature increase **(1)**

3

[9]

M15. (a) (i) $P_{out} = 0.36 \times 34.2 = 12.3$ kW **(1)**

(ii) $P_{farm} = 12.3 \times 2.5 = 30.8$ kW **(1)**

(iii) $P_{stream} = 30.8 - 12.3 = 18.5$ kW **(1)**

3

(b) **two** reasons in support of either choice

heat pump **(1)**

both systems use the same fuel so cost of same amount of fuel is same **(1)**

heat pump uses less fuel for the same output **(1)**

(or gives greater output for same amount of fuel **(1)**)

can also use energy rejected from engine for heating **(1)**

max 3

[6]

M16. (a) (i) work done = area enclosed by curve ABCD = 20 kJ (± 2kJ)**(1)**

satisfactory method used to find area e.g. counting squares **(1)**

correct scaling factor used (e.g. 1 small square = 40 J) **(1)**

(ii) power = 20 kJ per cycle × 3 cycle per second = 60 kW (± 6 kW) **(1)**

(iii) input power (= fuel flow rate × calorific value)
$= 2.4 \times 10^{-2} \times 34 \times 10^{6} = 816$ kW **(1)**

efficiency = $P_{out}/P_{in} = \dfrac{60 \times 10^3}{816 \times 10^3} \times 100 = 0.07$ or 7% **(1)**

6

(b) modified engine:

same mass of steam required

less fuel required because of recycled heat

greater work output per cycle because loop larger

same speed so greater power output

greater efficiency as P_{out} is greater and P_{in} less

(1)(1)(1) any three

3

[9]

M17. (a) (use of pV^{γ} = constant gives)

$1.01 \times 10^5 \times (4.25 \times 10^{-4})^{1.4} = 1.70 \times 10^5 \times V^{1.4}$ **(1)**

V calculated correctly (= 2.93×10^{-4} Pa) **(1)**

2

(b) $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ **(1)**

T_1 = 273 + 23 = 296 (K) **(1)**

$T_2 = \frac{1.7 \times 10^5 \times 2.93 \times 10^{-4} \times 296}{1.01 \times 10^5 \times 4.25 \times 10^{-4}}$ **(1)** = 343 K (70°C) **(1)**

4

[6]

M18. (a) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate correctly identifies the two adiabatic and two constant volume processes described in their correct sequence and gives detailed consideration of where heating, cooling and work transfers take place. The candidate states that work is done on the gas only in A → B and by the gas only in C → D, and/or states that the area of the loop is net work done. There is also some reference to temperatures and pressures increasing or decreasing

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.

The candidate correctly identifies where some of the heat and work transfers take place but the answer is much more limited. The adiabatic processes may not be named as such, but there is a statement that work is done in these processes **or** that there is no heat transfer. One process might be missed out altogether or be incorrect. There may be reference to temperatures, volumes and pressures increasing or decreasing.

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.

The candidate may refer (incorrectly) to the four processes as making up the four strokes of the engine real engine and some credit may be given if there is a statement that A → B is the compression stroke and C → D is the power stroke.
The answer may be written mainly in terms of pressures, volumes **and temperatures** increasing or decreasing with little reference to the type of process or heat or work transfers.
The candidate may relate the answer to a real engine rather than the theoretical cycle eg 'the spark occurs at B'

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

A to B work done **on** air
adiabatic compression
no heat transfer (from air)
temperature rises

B to C no work done
heating at constant volume
temperature rises (and also pressure)

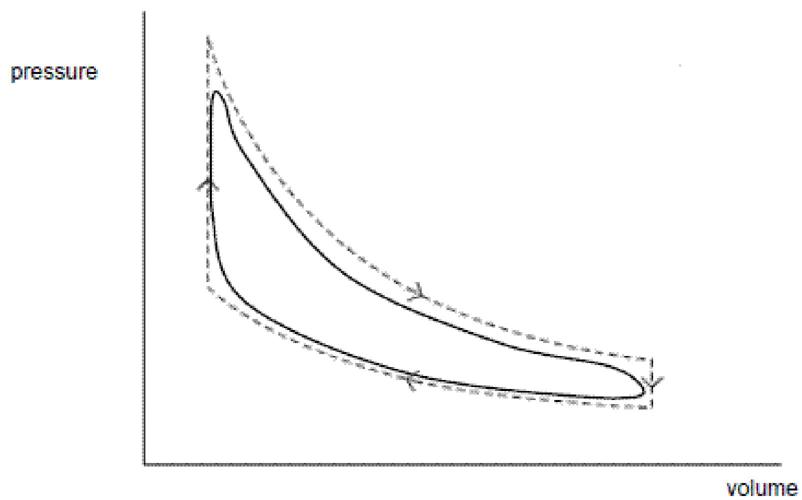
C to D work done by air *accept power stroke*
adiabatic expansion
no heat transfer (to air)
work done at expense of kinetic energy of molecules

D to A cooling (or heat rejected) at constant volume
with no work done
temperature falls

accept answers which cover above points and include reference to piston, cylinder, valves

max 6

(b)



induction and exhaust 'pumping' loop shown **(1)**

loop of smaller area than ideal loop with 'rounded' corners **(1)**

2

[8]

M19. (a) work done = area under line **(1)**

appropriate method for finding area eg counting squares **(1)**

correct scaling factor used (to give answer of 150 J ± 10 J) **(1)**

if candidate correctly calculates area under curve to a pressure of zero Pa, (330 J ± 20 J) award 2 marks

3

(b) if isothermal line would have been less steep **(1)**

(so greater area under line and) more work done **(1)**

so rocket would rise higher **(1)**

3

[6]

M20. (a) (refrigerator operates between a cold space and a hot space)

Q_{out} is the energy removed from the fridge contents (or from the cold space) **(1)**

Q_{in} is the energy given to the surroundings (or to outside the fridge/hot space) **(1)**

2

(b) (i) power for cooling ice = 5.5 × (420 × 10^3)/3600 = 642 W **(1)**

P_{in} = 642/4.5 = 142 W **(1)**

or energy taken from ice in 1 hour = 5.5 × 420 × 10^3 = 2310 kJ

W_{in} = 2310/4.5 = 513 kJ **(1)**

$$P_{in} = \frac{513 \times 10^3}{3600} = 142 \text{ W}$$ **(1)**

2

(ii) Q per s = 142 + 642

= 784 W (give CE) **(1)**

or $Q_{in} = Q_{out} + W_{in}$ = 513 kJ + 2310 kJ = 2820 kJ

Q_{in} per s = $\frac{2820 \times 10^3}{3600}$ = 784 W **(1)**

1

[5]

M21. (a) (i) 3.2 × 780 = 2500 W ✓

1

(ii) 2500 – Q_{out} = 780

Q_{out} = 1720 W ✓

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

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]

M22. (a) (i) use of PV/T = constant

$$\frac{P_D V_D T_A}{P_A V_A} \checkmark$$

$$= \frac{2.5 \times 1.0 \times 300}{1.5 \times 1.0} \checkmark = 500 \text{ K}$$

2

(ii) $Q = \Delta U + W$

$\Delta U = 0$ ✓

$Q = W = 173$ J ✓

2

(b) (i) work out = 173 – 104 = 69 J ✓

1

(ii) efficiency = 69/173 = 0.40 or 40% ✓

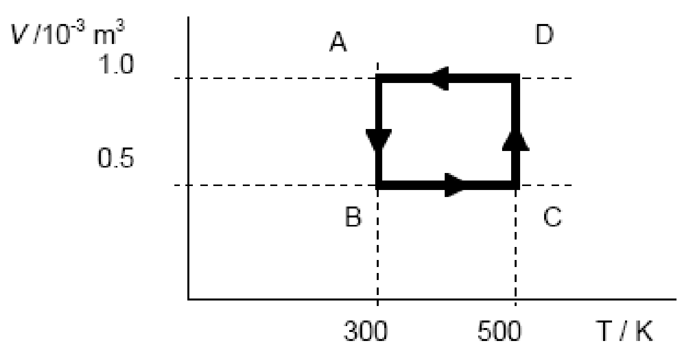
$\eta_{max} = (T_H - T_C)/T_H$

= (500 – 300)/500

= 0.39 or 40% ✓

2

(c)



rectangle in correct position ✓

letters correct place ✓ (arrows optional)

2

(d)
- isothermal process impossible unless very slow or via perfect conductor
- engine would have to stop for constant volume processes to take place
- regenerator would lose heat to surroundings (unless perfectly insulated)
- long time needed for heat to transfer from regenerator to working fluid
- regenerator would need to be very large/large surface area for heat transfer to take place quickly

  accept other sensible suggestions

  ***do not** accept 'heat loss to surroundings' or 'friction'*

any two ✓✓

2

[11]

M23. (a) (i) Indicated work per cylinder = area of loop ✓ [either stated explicitly or shown on the Figure e.g. by shading or ticking squares or subsequent correct working.]

appropriate method for finding area e.g. counting squares ✓

correct scaling factor used [to give answer of 470 J ± 50 J] ✓

indicated power = 4 × 0.5 × (4100/60) × 470

= 64 kW ✓

4

(ii) (Fuel flow rate = 0.376/100 = 0.00376 litre s^{-1})

Input power (= c.v. × fuel flow rate)

$= 38.6 \times 10^6 \times 0.00376$ ✓

(= 145 kW)

$\eta_{overall}$ = brake power/input power ✓ seen or implied from correct subsequent working

= 55.0/145 = 0.38 or 38% ✓

3

(b) Power expended in overcoming friction

in (all) the bearings / between piston & cylinder ✓

and / or in circulating oil / cooling water ✓

and / or driving auxiliaries (e.g. fuel injection pump) ✓

1

(c) Represents the induction <u>and</u> exhaust (strokes) (which take place at nearly atmospheric pressure). ✓

1

[9]

M24. (a) Either *W = area under (engine torque) graph from* 0 *to* 2π rad ✓

OR *W = area under graph because W = TΘ* ✓

OR *W = dynamo torque* × 2π ✓

OR *W = area under dotted line / dynamo torque because W = TΘ* ✓

1

(b) **The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.**

The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria.

High Level (Good to excellent): 5 or 6 marks

The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

The candidate is aware that at two points in the cycle the engine torque is zero and can give a reason, perhaps mentioning moments or variation in steam pressure

The candidate identifies the flywheel as a store of rotational kinetic energy and can relate the energy changes in one cycle to the varying torque and clearly relates the fluctuation in speed to the value of the M of I of the flywheel.

***Alternatively**, the candidate states that the flywheel tends to maintain angular momentum and so takes the crank over the dead centres. The changing torque has the effect of changing the angular momentum ($I\Delta\omega$) but if I is large, $\Delta\omega$ is small.*
The candidate may go on to discuss effect of I being very large (e.g long acceleration time from start).

Intermediate Level (Modest to adequate): 3 or 4 marks

The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate.
The candidate correctly identifies that a flywheel will make for smoother motion and may show an understanding that a flywheel acts as an energy reservoir, but may not be able to link the motion of the flywheel to the engine torque graph. Candidates answering in terms of angular momentum appreciate that the flywheel's angular momentum will take it over the dead centres. The candidate identifies that an increase in moment of inertia gives smoother running/less variation in speed per cycle. Reasons for the variation in torque may not refer to moments but candidate may state that torque is zero when crank and con rod are in line.

Low Level (Poor to limited): 1 or 2 marks

The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate.
The candidate may be able to give a reason why the motion is not smooth and can identify that a flywheel will make for smoother running. There may be some reference to the flywheel storing energy. They may confuse power or angular momentum with energy.

The explanation expected in a competent answer should include a coherent selection of the following points concerning the physical principles involved and their consequences in this case.

- without flywheel motion will be jerky/unsmooth/cause vibrations
  OR flywheel makes motion smoother/less fluctuation in speed
- flywheel needed to take crank over dead centres (wtte)
- because torque is zero at dead centres
- torque varies because pressure on piston varies
- because force is in line with c'shaft/ no moment of force about c'shaft
- flywheel stores rotational kinetic energy when engine torque > dynamo torque
- flywheel gives up energy when engine torque < dynamo torque
- flywheel's ang. momentum takes it over dead centres
- the greater I, the less the fluctuation in speed over one cycle
- over one cycle, work done by engine = work needed by dynamo
- so average engine torque = average dynamo (load) torque
- torque = rate of change of ang. momentum – high I gives less change in ω.

6

[7]

M25. (a) (i) $p_2 = p_1 (V_2/V_1)^{1.4} = 1.0 \times 10^5 (2.1/1.2)^{1.4}$ ✓

OR $1.0 \times 10^5 \times (2.1 \times 10^{-5})^{1.4} = p_2 \times ((1.2 \times 10^{-5})1.4$ ✓

$p_2 = 2.2 \times 10^5$ Pa ✓

2

(ii) $T_2 = \frac{p_2 V_2 T_1}{p_1 V_1} = \frac{2.2 \times 10^5 \times (1.2 \times 10^{-5}) \times 290}{1.0 \times 10^5 \times 2.1 \times 10^{-5}}$ ✓

OR use of $p_1V_1 = nRT_1$ to find n or nR and substitute in

$p_2V_2 = nRT_2$ to find T_2 ✓

T_2 = 360 K ✓ 2 sig fig ✓

3

(b) ($Q = W + \Delta U$)

Q = 0 (and W negative) ✓

So ΔU (= - W) = 1.4 J ✓

2

(c) (slow) compression is (nearly) isothermal / at constant temperature ✓

greater change in volume needed to rise to same final pressure ✓

(OR correct p-V sketches showing adiabatic and isothermal processes ✓)

hence less / piston pushed in further ✓

3

[10]

M26. (a) (A device in which) an input of work ✓

(causes) heat to transfer from a cold space / reservoir to a hot space / reservoir ✓

2

(b) Heat transfer to hot space equals work done plus heat transfer from cold space / $Q_{IN} = W + Q_{OUT}$

Either written statement or expressed in symbols

so Q_{IN} (is always) > Q_{OUT} *reason must be seen* ✓

$COP_{HP} = \frac{Q_{IN}}{W}$ and $COP_{REF} = \frac{Q_{OUT}}{W}$

So $COP_{HP} > COP_{REF}$ ✓

The COP formulae are in formulae booklet so no marks for simply quoting them. i.e 2nd mark cannot be awarded without first mark.

OR

$Q_{IN} = W + Q_{OUT}$ ✓

$COP_{HP} \times W = \quad + COP_{REF} \times W$ or $COP_{HP} = \frac{Q_{IN}}{W} = \frac{W + Q_{OUT}}{W}$

So $COP_{HP} = 1 + COP_{REF}$

So $COP_{HP} > COP_{REF}$ ✓

2

[4]

M27. (a) (Adiabatic change requires) no heat transfer / energy transfer / heat to escape / heat loss (to surroundings) ✓

Do not accept heat or energy 'change' .

(Compression stroke occurs in short time / very quickly) so no time for heat transfer ✓

(Therefore change can be considered to be adiabatic)

2

(b) (i) $P_1V_1^{\gamma} = P_2V_2^{\gamma}$

Significant figure mark is an independent mark

$1.0 \times 10^5 \times (4.5 \times 10^{-4})^{1.4} = 6.2 \times 10^6 \times V_2^{1.4}$ ✓

$V_2 = 2.4 \times 10^{-5}$ m^3 ✓ 2 sig fig ✓

3

(ii) use of

$$\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$$

CE from b i

$$T_2 = \frac{p_2V_2T_1}{p_1V_1} = \frac{6.2 \times 10^6 \times 2.4 \times 10^{-5} \times 297}{1.0 \times 10^5 \times 4.5 \times 10^{-4}}$$ ✓

If 2.36×10^{-5} m^3 used for V_2, T_2 = 966 K

OR use of *$n = p_1 V_1 / R T_1$ and $T_2 = p_2V_2 / nR$*

Leading to T_2 = 982 K ✓ **2**

(iii) So that the fuel has partially evaporated / started to burn when piston is at top of stroke (so max pressure obtained when piston is at top of stroke / top dead centre).

Accept 'diesel' instead of 'fuel'

OR If injected at top dead centre. by the time fuel has started to burn, piston would be on its way down cylinder, (so max possible pressure not obtained).

1

(c) **Good – Excellent**

The information conveyed by the answer is clearly organized, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question.

*The candidate gives a comprehensive account of the differences between the two cycles, **with reasons.** There are clear statements relating to the need for induction and exhaust processes / strokes in a real engine only, that adiabatic processes are not possible in the real engine, that constant pressure and constant volume processes are impossible, and / or that the corners of the real engine diagram are rounded.*

They will refer to the lower efficiency of the real engine, linking this to the smaller area loop, or the fact that the pumping loop has to be subtracted from the main loop and/or that heat transfers occur during compression and expansion and that in the real engine friction has to be overcome / power has to be expended in driving ancillaries.

5-6

Modest – Adequate

The information conveyed in the answer may be less well organized and not fully coherent. There is less use of specialist vocabulary or specialist vocabulary may be used or spelled incorrectly. The form and style of writing is less appropriate.

The candidate's comparisons are less complete but good understanding is shown of some of the major differences between the diagrams, with some reasons given.

They should be able to give at least one valid reason for the lower efficiency of the real engine cycle.

3-4

Poor – Limited

The information conveyed by the answer is poorly organized and may not be relevant or coherent. There is little correct use of specialist vocabulary.

The candidate is more likely to describe the differences rather than explain them. They are likely to make reference to the rounded corners, and the induction / exhaust strokes in the 'real' diagram, but not be able to say why these do not exist in the theoretical diagram. They may not be able to give a valid reason for the lower efficiency of the real engine cycle, or may give vague reasons in terms of 'heat losses' or 'friction' without further detail.

The descriptions and explanations expected in a good answer should include several of the following physics ideas

- Real engine needs 'pumping loop' at near atmos. pressure for induction and exhaust
- Work needed for induction and exhaust – so efficiency lower than theoretical
- Area of pumping loop has to be subtracted from main loop, hence reducing net work and hence efficiency of real engine
- Theoretical cycle needs no pumping loop / same air continuously taken through repeated cycles
- Corners rounded on real engine diagram [because valves are needed and take finite time to open/close]
- Cooling cannot occur at constant volume in real engine [because piston would have to stop]
- Heating does not occur at constant pressure [because impossible to control rate of burning of fuel during injection]
- Compression and expansion do not take place infinitely quickly heat is lost; therefore not adiabatic processes, lowering efficiency
- Area of loop is smaller for real engine, less work done per cycle so lower efficiency
- Friction between moving surfaces has to be overcome / energy expended in driving oil and water pumps, opening and closing valves etc.
- Always some exhaust gases present in cylinder.
- Theoretical cycle does not make reference to any mechanism
- Calorific value of fuel is never fully realised

2-1

[14]