AQA A-LEVEL PHYSICS · 7408

PHYSICS



MARK SCHEME

3.11.2 THERMODYNAMICS AND ENGINES

SCORE	PERCENTAGE
/106	%

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answers

Example *550/1000 = 0.55 or 55%; 640/1000 =.64 or 64%*

Increase in efficiency = 9%

Values for input energy must > 640 J

5

(c) Q: energy supplied/transferred/input (to system/gas by heating/heat transfer) ✓

OR energy transferred/lost/output (from system/gas by cooling heat transfer) if Q negative

ΔU: increase/change in internal energy ✓

OR decrease if negative

Do not allow 'heat' in place of 'energy'

'Heat transferred' on its own is not enough

Accept heat energy supplied but not heat supplied

2

(d) $W = p\Delta V = 1.0 \times 10^5 \times (3.00 - 1.50) \times 10^{-3}$ J (= 150 J) ✓

(Use of $Q = \Delta U + W$)

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gives $Q = -150 + (-374) = (-)\ 524$ J ✓

Check that sign convention is consistent for 2nd mark

Allow if − sign not seen on answer line

2

(e) Attempt to use $pV = nRT$ ✓

Recognises max temperature is at point **3** in the cycle ✓

Substitution of p, V and n in $T = \frac{pV}{nR}$ for point 3

Giving $T = 1310$ K ✓

2nd mark can be implied from values of p and V used in the equation

p from ***14 .2 × 10^5*** *to* ***14.8 × 10^5*** *Pa*

V from ***0.42 × 10^{-3}*** *to* ***0.48 × 10^{-3}*** *m^3*

3

[13]

Q2.

The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Level	Criteria	QoWC
6 marks	Both bullets in question are answered. Answer includes 8 or more points taken from both lists opposite and table below including use of data. Comes to a conclusion or advice given.	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.
5 marks	A fair attempt to answer both bullets. Answer includes 7 points taken from both lists opposite and table below including use of data. Answers will not be as full as for 6 marks. Comes to a conclusion or advice given.	
4	Makes some attempt to use the numerical data correctly. Answer includes any 5 or 6 of the points opposite or in table below.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.
3	Any 4 of the answer points opposite or in table below are given. May not make use of numerical data.	
2	2 or 3 answer points opposite or in table below are covered.	The student presents some relevant information in a

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	May not make use of the numerical data.	simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.
1	Any one pertinent statement.	
0	No sensible statements made.	The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.

Likely answer points:

First bullet

1. All heat engines must obey 2nd Law of thermodynamics

2. They must reject energy to a sink/surroundings (at low temperature)

3. Maximum efficiency determined by source and sink temperatures / formula quoted $\eta = T_H - T_C / T_H$

4. 100% efficiency would require $T_C = 0$ *K and/or a small difference between* T_H *and* T_C *gives low efficiency*

5. Allow: inefficiencies from nature of working cycle, friction, incomplete combustion etc.

Second bullet

6. 60 MW will cover electrical need (but not much margin for expansion)

7. Input power = 57/0.36 = 158 MW (or 167 MW at 60 MW output)

8. Max heat available for heat requirement = 101 MW (or 107 MW at 60 MW output)

9. And likely to/will be less than this

10. This is not enough for heating requirement

11. (At least) 34 MW will need to come from National Grid

12. Power station input to give 198 MW to mill = 495 MW

13. Energy <u>that would otherwise be wasted</u> is utilised.

Other answer points (other factors) for 2nd bullet are in the table below; credit sensible alternatives

National Grid		**CHP**	
advantages	**disadvantages**	**advantages**	**disadvantages**
No need to build power plant in mill - capital saving.	Cost /kWh includes cost of waste heat at power station and transmission cost.	Can provide all (average) electric power and most of heating need.	Space/land needed for installation.
High probability of uninterrupted supply.	Subject to power cuts.	Independent of any National Grid supply problems.	Maintenance and depreciation costs.
		Can sell any excess electrical power to grid.	Not all heating need can be supplied by CHP.
		Gives lower overall carbon footprint	Spikes in production may require more than 60 MW

[6]

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Q3.

(a) $p_1V_1^{1.4} = p_2V_2^{1.4}$

$p_2 = p_1 (V_1/V_2)^{1.4}$

$= 1.2 \times 10^6 (9.0/6.8)^{1.4}$ ✓ $= 1.8 \times 10^6$ (Pa) ✓

$$T_2 \frac{p_2V_2T_1}{p_1V_1} = \frac{1.8\times10^6\times(6.8\times10^{-5})\times290}{1.2\times10^6\times(9.0\times10^{-5})}$$ ✓

$T_2 = 328$ (K) ✓

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 ✓

1st mark for substituting correct values into either equation
2nd mark for answer p_2
3rd mark for substituting correct values into

$p_1V_1/T_1 = p_2V_2/T_2$ or $T_2 = \frac{p_2V_2T_1}{p_1V_1}$
4th mark for answer T_2
ECF for p_2
With rounding answers range from 320 to 330 K

4

(b) in adiabatic compression there is no heat transfer/$Q = 0$ ✓

If compression is quick there is no time for heat transfer ✓

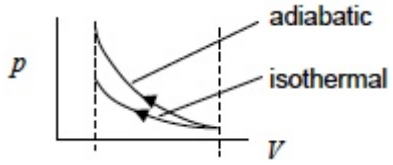
(so can be considered adiabatic)

2

(c) For isothermal compression (for same volume change) (final) pressure not as high **OR** adiabatic compression curve is steeper (on p - V diagram) than isothermal ✓
Area under a p - V curve between same volumes would be less OR addition of all $p\Delta V$ during compression will be less ✓

So less work done ✓

Give credit for these ideas shown with help of a diagram or diagrams.



Award last mark only if either or both of first two marks have been given.

3

[9]

Q4.

The mark scheme gives some guidance as to what statements are

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expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer.

Guidance provided in section 3.10 of the 'Mark Scheme Instructions' document should be used to assist in marking this question.

Mark	Criteria	QoWC
6	Both bullets in question are answered. Answer includes 9 or more points taken from both lists opposite with reasons mainly matching differences. Allow for answers which state the events in both cycles, provided points alongside are covered and some reasons given for differences.	The student presents relevant information coherently, employing structure, style and SP&G to render meaning clear. The text is legible.
5	A fair attempt to answer both bullets. Answer includes 7or 8 points taken from both lists, including at least two matching reasons for differences. Answers will not be as full as for 6 marks.	
4	Comparisons are less complete but good understanding is shown of the differences between the diagrams. Answer includes 5 or 6 of the points opposite with at least one taken from each part.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. SP&G are sufficiently accurate not to obscure meaning.
3	The student will address 4 or 5 of the points listed but reasons may not be given with confidence or reasons may not match the differences	
2	Fewer than 4 points are covered. The student is more likely to state the differences rather than	The student presents some relevant information in a simple form. The

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	explain them. The answer addresses one or both bullets in the question but with limited scope. They are likely to refer to 'heat losses' or 'friction' without detail.	text is usually legible. SP&G allow meaning to be derived although errors are sometimes obstructive.
1	Some attempt is made to compare the cycles.	
0	No relevant information.	The student's presentation, SP&G seriously obstruct understanding.

The following statements are likely to be present.

First bullet: differences between cycles

- Real engine needs induction and exhaust strokes/ pumping loop
- Ideal cycle needs no pumping loop/same air used repeatedly
- Corners rounded on real cycle
- Reason: valves take finite time to open and close/combustion not instantaneous
- Heating/cooling cannot occur at constant volume in real cycle
- Reason: piston would have to stop
- In real cycle expansion & compression are not adiabatic
- Reason: heat transfer takes place to cooling medium during these strokes
- In ideal cycle air only is taken through cycle (repeatedly)/gas is ideal
- In real engine some exhaust gas/fuel vapour is present/gas is not ideal
- Max pressure is lower in real engine
- Fuel may not be completely burnt
- Ideal cycle makes no reference to any mechanism
- In real engine a mechanism is necessary e.g. for valve operation, generation of spark

Second bullet: why work output less

- Area of loop is smaller for real engine, so less work done per cycle
- Area of pumping loop has to be subtracted from main loop, reducing work done
- Friction between moving surfaces/between piston & cylinder/in bearings has to be overcome
- energy is expended in driving oil and water pumps, opening and closing valves overcoming fluid viscosity etc

Accept other reasonable answers in lieu (e.g. variation in γ during

expansion and compression).

[6]

Q5.

(a) Tick against answer B ✓

1

(b) COPref = $\frac{272}{343 - 272}$ (= 3.8 (3.83)) ✓

$3.8 = Q_C/(100 - Q_C)$ giving Q_C = 79 (W) (79.3W) ✓

P_{IN} = 79/3.8 = 21 (W) (20.7 W) ✓

OR for 2nd and 3rd marks

COPref = Q_C/W and $Q_C + W = Q_H$ = 100 ✓
3.8 $W + W$ =100
So W = 21 (W) ✓

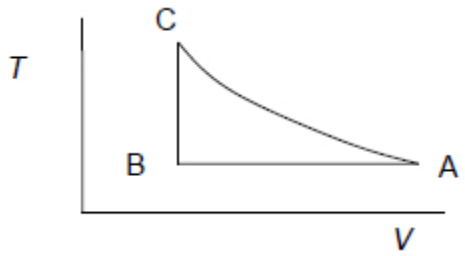
OR for 2nd and 3rd marks
COPhp = COPref + 1 ✓
$W = Q_H/4.8$ = 100/4.8 = 21 (W) ✓

3

[4]

Q6.

(a)



Shape ✓

Labels ✓

CA must be a curve.

2

(b) Work done (per cycle) = area of indicator diagram ✓

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

Correct scaling factor leading to area = 70 J ± 10 J ✓

1 small sq = 0.4 J.
1 large sq = 10 J.
Other methods accepted e.g. strips.

3

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(c) 'Answer to part **(b)**' × 80 correctly evaluated ✓

1

(d) **The mark scheme gives some guidance as to what statements are expected to be seen in a 1 or 2 mark (L1), 3 or 4 mark (L2) and 5 or 6 mark (L3) answer. Guidance provided in section 3.10 of the *Mark Scheme Instructions* document should be used to assist marking this question.**

L3 5-6 marks	Both parts of the question are addressed in detail with some quantification of the efficiency, either ideal, actual or both. The answer includes at least 8 answer points from the list below.	The student presents relevant information coherently, employing structure, style and sp&g to render meaning clear. The text is legible.
L2 3-4 marks	The answer includes some discussion related to each part. The answer includes 5 - 7 of the answer points below.	The student presents relevant information and in a way which assists the communication of meaning. The text is legible. Sp&g are sufficiently accurate not to obscure meaning.
L1 1-2 marks	The answer addresses one part in some detail but efficiency may not be quantified. There may be consideration of up to 4 of the answer points below.	The student presents some relevant information in a simple form. The text is usually legible. Sp&g allow meaning to be derived although errors are sometimes obstructive.
0 marks	Little or no discussion of relevant content.	The student's presentation, spelling, punctuation and grammar seriously obstruct understanding.

- *CA would have to be very fast to ensure no heat transfer.*
- *AB would have to be very slow to ensure constant temperature.*
- *very difficult to arrange a slow 'stroke' and a fast 'stroke' in one engine.*
- *Output speed would vary over a cycle.*
- *Difficulty in arranging for end of expansion and start of compression to occur at one point.*
- *For heating at constant volume, engine would have to stop, or combustion be very fast.*
- *Max poss efficiency is (590 - 295)/590 = 0.5 or 50%.*
- *Actual efficiency of this ideal cycle = 43/251 = 0.17.*

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- *Real efficiency will be << these efficiencies and much less than engines currently available.*
- *Power output is very small for a 1 litre engine so **not** wise to go ahead*

6

[12]

Q7.

(a) (device in which) an <u>input</u> of work ✓

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

Answer must indicate that work is input OR done on working substance.

2

(b) Q_H is energy into the hot space / reservoir / space to be heated

1

(c) $0.5 = \frac{(T_H - T_C)}{T_H}$ ✓

$COP_{HP} = \frac{T_H}{T_H - T_C} = \frac{1}{0.5} = 2$ ✓

2

[5]

Q10.

(a) $1.01 \times 10^5 \times (1.0 \times 10^3)^{1.4} = 8.25 \times 10^4 \times V_2^{1.4}$ ✓

Leading to $V_2 = 1.16 \times 10^3$ m^3 or 1160 m^3 ✓

1st mark: or for rearranging the equation first and correct numbers seen.

The sig fig mark is an independent mark but some working must be shown.

3

(b) (25 °C = 298 K)

$p_1V_1/ T_1 = p_2V_2/T_2$ with correct *p, V, T* substituted

OR

$T_2 = p_2T_1/ p_1V_1$ with correct *p, V, T* substituted ✓

T_2 = (282 K) = 9.0 °C ✓

298 - 282 or 25 - 9 = 16 K

16/9.8 = 1.6(3) km ✓

Accept use of $p_1V_1 = kT_1$ and

$T_2 = p_2V_2 / k$

Answer line requires T_2 in °C but accept in K if student has

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changed the unit on answer line to K.
*Allow CE for third mark using student's T_2 but must use temperature **change**.*

3

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

(in adiabatic expansion) $Q = 0$ ✓

W is +ve so $W = -\Delta U$ meaning internal energy decreases

OR work is done at expense of internal energy [WTTE] ✓

(internal energy related to T) therefore T falls. ✓

For 1st mark do not allow Q is constant / no change
Ignore Δ if used with Q or W
Do not accept 'thermal' energy for internal energy.

3

[9]

Q11.

(a) Diesel: air only is drawn into cylinder
Petrol: air and fuel is drawn into cylinder both points ✓
Diesel: ignition is by temperature rise during compression / compression ignition
Petrol: ignition by means of spark (plug) both points ✓

Accept: heating at constant volume in (ideal) petrol engine and constant pressure in (ideal) diesel engine ✓
Do not allow: petrol engine has spark plug, diesel doesn't WTTE

2

(b) (i) **X** marked on curved compression line between $p = 0.7 \times 10^6$ Pa and 1.7×10^6 Pa ✓

1

(ii) Indicated work = area of loop ✓
Appropriate method for finding area e.g. counting squares ✓
Correct scaling fact or used to give work per cycle of between 250 and 325 (J) ✓
(Calculates no cycles per s (½ × 2000/60) = 16.7)

$P = 4 \times 16.7 \times 287 = 19.2$ kW ✓

Either stated explicitly or shown on Figure e.g.
by shading or ticking squares or subsequent correct working.
287 small squares is a good estimate.
Scaling factor is 1 J per small square
Allow 10 to 13 1 cm squares
Scaling factor is 25 J per 1 cm square
CE for 4th mark using incorrect work per cycle

4

(iii) Input power = CV × fuel flow rate

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$= 44 \times 10^6 \times (1.1 \times 10^{-3})$ (= 48.4 kW) ✓

$\eta_{thermal} = 19.2/48.4 = 0.40$ ✓

CE from 4 b ii unless $\eta_{thermal} > 1$

2

(c) Tick against second answer line ✓

1

[10]

Q12.

(a) **E** to **X** circled

1

(b) (i) $p_1V_1 / T_1 = p_2V_2 / T_2$

$T_2 = p_2V_2T_1 / p_1V_1$ ✓

$$= \frac{4.6\times10^5 \times 1.5\times10^{-4} \times 310}{1.0\times10^5 \times 5.0\times10^{-4}}$$

=430 K ✓

Also: work out n or nR in $p_1V_1 = nRT_1$

Substitute in $p_2V_2 = nRT_2$

Accept use of 4.5×10^5 Pa for p_2

Giving $T_2 = 420$ K

nR = 0.161

$n = 1.94 \times 10^{-2}$

2

(ii) Work per cycle = area enclosed by loop ✓

Suitable method for calculating area used correctly e.g. counting squares ✓

E.g. 355 small sq × 0.2 × 10^5 × 0.1 × 10^{-4}

OR

14 × 1 cm squares × 1.0 × 10^5 × 0.5 × 10^{-4}

Correct scaling factor used leading to 70J ± 5 J ✓

If no. of squares incorrectly counted but correct scaling factor used for their squares give CE for final answer

3

(iii) P = 70 × 420 / 60 = 500 W ✓

CE from ii

1

(iv) Marks awarded for this answer will be determined by the Quality of Written Communication (QWC) as well as the standard of the scientific response.

0 marks

The information conveyed by the answer is sketchy, and neither relevant nor coherent.

The candidate shows inadequate understanding of the operation of the

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compressor and how its performance will change.

Level 1 (1−2 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 candidate has some appreciation of how the performance will change, but is only likely to cover **up to three** of the points listed below, and probably without reasons.*

Level 2 (3−4 marks)
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 is able to make some correct predictions concerning how the diagram, work done, power and temperature (but not all) will change, but reasoning will be less confident.
Answers will include 4 to 6 of the points listed below.

Level 3 (5−6 marks)
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.
A good attempt is made at how the compressor will operate at higher pressures. Statements are made relating to the diagram, work or power, temperature and flywheel, backed up by some sound reasoning.
Answers at this level will include more than 6 of the points listed below.

examples of the points made in the response

1. area of loop increases as p increases
2. BC at higher pressure / point B moves up and to left
3. p higher in $W = p\Delta V$ for BC / higher p more work to force air into tank
4. (so) work done per cycle increases
5. input power increases (if speed constant)
6. temperature will increase
7. reason: because B gets further from graph origin / $p_2V_2$gets larger / int energy increases because little time for heat transfer
8. higher p means more applied crankshaft torque (between dead centres)
9. so jerkier motion
10. flywheel needed to smooth motion of crankshaft
11. flywheel acts as energy store
12. speeding up / gaining energy - then slowing down / losing energy when torque needed is high / takes piston over dead centres
13. application of $T = I\alpha$: fluctuations in ω small if I large
14. expansion of air in clearance volume will have negative effect on area
15. vol of air drawn in per cycle will decrease
16. increase in work per cycle gets progressively smaller as p increases

check to see if Fig 3 drawn on

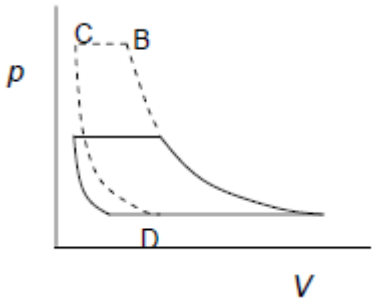
Bullet points 1, 14 and 15 can be supported by diagram

Expect to see: BC to be at higher pressure and loop to get

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narrower

Candidates are unlikely to show the effect of clearance volume (CD)



Point 6: accept correct use of pV/T constant

14,15,16 unlikely but give credit in lieu of other points

6

[13]

Q13.

(a) $T_H = 273 + 540 = 813$ K

$T_C = 273 + 25 = 298$ K ✓

$\eta_{max} = (813 - 298) / 813 = 0.633$ 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 = $\frac{\text{output power}}{\eta_{max}}$

Give CE from (a) unless $\eta_{max} > 1$

$= \frac{48.0}{0.633}$ = 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 ✓✓

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2

[5]

Q14.

(a) (i) Appreciates *pV* should be constant for isothermal change (by working or statement) $W = p\Delta V$ is TO

Allow only products seen where are approximately 150 for 1 mark
Penalise J as unit here

M1

Demonstrates *pV* = constant using 2 points (on the line) set equal to each other or conclusion made or **shows** that for V doubling that *p* halves (worth 2 marks)
need to see values for p and V

Products should equal 150 to 2 sf
Accept statement that products are slightly different so not quite isothermal

A1

Demonstrates *pV* = constant using 3 points (on the line) with conclusion
Need to see values for p and V

Products should equal 150 to 2 sf
Accept statement that products are slightly different so not quite isothermal

A1
3

(ii) Adiabatic therefore no heat transfer **or**
Adiabatic therefore *Q* = 0

B1

Work is done by gas therefore *W* is negative **or**
Work is done by gas therefore energy is removed from the system

B1

ΔU is negative therefore internal energy of gas decreases **or** energy is removed from the system therefore internal energy of gas decreases or work done by the gas so internal energy decreases

Allow
$-\Delta U = -W$ *or* $\Delta U = -W$

B1
3

(iii) Uses pV / T = *constant or uses* $pV = nRT$ *or uses*

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$pV=NkT$

e.g. makes T subject or substitutes into an equation with p_A and $V_A$or p_C and V_C (condone use of n = 1) or their $\frac{(pV)_A}{(pV)_C}$

V_a *read off range*
= 2.5 to 2.6 (× 10⁻⁴)
p_A *= 600 × 10³*
V_C *read off range*
= 8.5 to 8.6 (× 10⁻⁴)
p_C *= 140 × 10³*

C1

Correct substitution of coordinates (inside range) into $\frac{(pV)_A}{(pV)_C}$
With consistent use of powers of 10

$(pV)_A$ range is 150 to 156 and $(pV)_C$ range is 119 to 120.4

C1

1.2(5) Allow range from 1.2 to 1.3

Accept decimal fraction : 1

A1
3

(b) Energy per large square = 10(J) **or** states that work done is equal to area under curve (between A and B)
or energy per small square = 0.4(J)
or square counting seen on correct area

Must be clear that area represents energy either by subject of formula or use of units on 10 or 0.4

Alternative:
W = area of a trapezium
(with working)
or *W =* P_{mean} *× Δ*V ***or***
W = 450 × 10³ × 2.5 × 10⁻⁴
or *W = area of a rectangle + area of a triangle (with working)*

B1

Number of large squares = 10.5 to 11.5 seen and (W) =
number of squares × area of one square (using numbers)
Range = 105 to 115 (J)
Or

Number of small squares = 263 to 287 seen and (W) =

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number of squares × area of one square (using numbers)
Range = 105 to 115 (J)

States that actual work done would be lower because of curvature of line

B1
2

(c) (Total energy removed per s =) 4560 (J)
or number of cycles per s = 40
or (Mass per second =) 114 ÷ 68400 in rearranged form
or their energy ÷ (c ΔT) **or** their energy ÷ 68400

C1

0.067 (kg) seen Allow 0.066 (kg) here
or allow V / t = $1.67 \times 10^{-3} \div 1100$
or ($\frac{V}{t}$) = $\frac{E}{\rho c \Delta\theta}$ and correct **substitution** seen

Condone E = 114 (J) **or** temperature = 291(K)

C1

= 0.061×10^{-3} or 6.06×10^{-5} (m^3)

A1
3

[14]

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Q1.

(a) The mark was scored by 47.1% of the students.

(b) This question concerned the work done and efficiency of a modified ideal diesel engine cycle. Students were asked to make judgements about the two claims given in the question. Estimating the extra work done for Claim A caused few problems for most students. Counting squares was the most common method but, as an alternative, full credit for the calculation could be gained by approximating the area 1 → 4 → 5 → 1 to a triangle. Of those who knew what they were doing in Claim B, many failed to gain a mark by under- estimating the area of the loop 1 → 2 → 3 → 4 → 1. This did not, however, prevent them from scoring subsequent marks. The examiners accept that there was some ambiguity in the question. An alternative mark scheme was prepared to account for those who attempted to calculate separate efficiencies for both cycles, and then found the increase. The question should have given either the efficiency of the first cycle, or its input energy. Only a minority of students tried this approach, and examiners took pains to ensure no students were disadvantaged. 30.5% of students scored four or five marks; 51.2% scored one, two or three marks. Teachers of this option might like to know that this question was about an Atkinson cycle, a variation of which is used in some modern car engines to improve fuel consumption.

(c) There were many disappointing answers to this question. All too often, Q was defined as “heat”, “heat flow” or “heat transfer”, with no mention of the word 'energy'. It is to be expected that students taking an option specialising in thermodynamics would have a strong understanding of the first law of thermodynamics, and not be sloppy in their definitions. Some wrote "total energy", probably because it was the sum of two entities, ΔU and W. About 39% scored one mark out of the two, mainly because their understanding of the meaning of ΔU was much better. 18.4% of the students scored no marks at all. There were instances where the terms internal energy, heat and temperature were used as if they meant the same thing.

(d) Answers here reinforced the examiners' view (from part (c)) that the first law is not fully understood. 21.5% of students scored both marks, but another 35.8% could only score the one mark for calculating the work done in process 5 → 1 (with or without the minus sign). This is work done **on** the air, so must be **negative** in $Q = \Delta U + W$. The calculations “−374 J + 150 J = −224 J”, or “374 J −150 J = 224 J”, were commonly seen.

(e) The majority of students who judged correctly that the highest temperature in the cycle was at point 3 were able to score full marks (45.8% of students), but some failed to gain the last mark by not reading accurately enough the pressure and volume at point 3 on Figure 4. The first mark was an 'easy' mark for attempting to use $pV = nRT$, for example by using any point in the cycle. Despite this, nearly 10% of the students scored zero, and 8.2% did not attempt the question. Many students had no idea which point in the cycle corresponded to maximum temperature, so were unable to access the second and third marks.

Q2.

This question was answered well by those students who had a good understanding of the meaning of efficiency and who had previously come across the idea of combined heat and power (CHP). These students were able to explain the upper limit of efficiency of a heat

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engine, often quoting $(T_H - T_C)/T_H$ and sometimes mentioning the second law of thermodynamics. They then went on to address the paper mill CHP scheme using the data given. The most common points made using the data were that:

- when all the energy required by the mill came from the National Grid, the corresponding input energy would be 495 MW;
- the input energy to the generator is 158 MW or 167 MW (depending on whether they used a generator output of 57 or 60 MW);
- the energy in the exhaust gases (101 or 107 MW) is not enough to provide all 141 MW for process heating;
- the generator can provide the 57 MW load for all the electrical equipment and offices.

came up with arguments concerning the economics of the scheme (capital, installation, maintenance and staffing costs) and reliability. The marking was generous at the lower end. Students could score a mark for practically any sensible reason for low efficiency of a heat engine, even though the question related to maximum theoretical efficiency. Some wrote half a page on reasons for low efficiency of 4 stroke engines, which were not relevant here. The concept of efficiency is in the main part of the specification (Section 3.4.1.7) and in the option, but a significant number of students showed a lack of understanding. For example, the output power of the generator was given in the question as 60 MW, but this did not stop students calculating the output as 60 × 0.36 or 21.6 MW. A common recommendation was to use the National Grid because it could easily supply all the power needed, completely missing the idea of making use of energy that would otherwise be wasted. Just over three-quarters of the students were awarded at least two out of the six marks available; however, only 4% gained full credit.

Q3.

(a) The majority of students scored 2 marks here for calculating the final pressure, but the calculation of final temperature proved more difficult. A minority of students thought the temperature remained constant. The expected route to the temperature was to use PV/T = constant, but a very small number of students used $T \times V^{\gamma-1}$ = *constant*, which is correct, but more likely to incur an arithmetical error.

(b) Here, the mark scheme required students to define an adiabatic process and then state that there was little time for heat transfer to take place when the pressure is rapid. Only 30% of students scored both marks.

(c) Students who wrote the best answers to this question took the hint from the space given above the answer lines to draw a $p - V$ diagram, clearly showing adiabatic and isothermal curves for compression, through a fixed volume change, starting from a common point. In their written answers they then referred to the areas under the curves. All too many students tried to argue their way through this by applying the first law of thermodynamics to both processes, and got nowhere.

Q4.

In this level-of-response question, students were asked to compare a theoretical Otto cycle with a real petrol engine cycle. Just under half of all students scored 4, 5 or 6 marks, indicating a good understanding of the differences and the reasons for the differences, and also an understanding of why the work output is lower than the theoretical cycle predicts. It is likely that these students and/or their teachers had read the Engineering Physics teaching guide to be found on the AQA website.

For level 3, the differences between the cycles needed to be given matching reasons, but for levels 1 and 2, candidates could pick up marks for any points taken from the lists given

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in the mark scheme. There were some excellent answers at the top end, but at level 1 some students concentrated on what went on in the cycles rather than comparing them. Simply by noting the lower peak pressure, the induction/exhaust loop, the rounded corners and the smaller area, students could achieve credit. Common misconceptions were:

- the theoretical cycle is 100% efficient;
- the theoretical cycle doesn't lose heat, whereas a real engine does.

Q5.

(a) Half of all students scored the 1 mark for this question.

(b) Only about one third of all students scored any marks at all for this question. Of these, many were able to calculate the COPref from the absolute temperatures, but could get no further because they had little idea of the meanings of Q_C, Q_H, and W in the equations in the specification and Data Booklet. Common errors were:

- not changing temperatures from °C to K when calculating the COP;
- using the formula for the maximum efficiency of a heat engine rather than the idea of COP;
- to find the input power, multiplying the COPref by 100 or dividing 100 by the COPref;
- mixing temperature and energy in the same equation e.g. $W = 272/\text{COPref}$. Some students may not have been aware that the formula for calculating the COP using temperatures is in the specification, but not in the Data Booklet.

Q10.

The majority of students were able to do the calculation for part **(a)** successfully, including giving their answer to 3 significant figures. In part **(b)** a surprising number of students failed to convert 25°C to K. A carried error was given for those who had failed to calculate V_2 correctly in part **(a)**, but this often led to some unfeasible answers for the temperature near the top of the mountain, which students failed to question. Most realised that the answer required on the answer line was in °C. To calculate the height, far too many failed to use the information that the temperature change between the bottom and top of the mountain had to be divided by the adiabatic lapse rate.

Part **(c)** asked students to explain the temperature drop of the air pocket by referring to the first law of thermodynamics. There were many full and succinct answers, with a clear indication of the meaning of the terms Q, W and ΔU and how they apply in the situation described. Many were not careful enough to distinguish between internal energy and temperature and some answered in terms of Q remaining constant instead of being zero. A minority tried to answer with no reference whatsoever to the first law.

Q11.

In part **(a)** students were asked for basic differences in operation between diesel and petrol engines. The examiners were looking for the different methods of ignition and the fact that the diesel engine compresses air, whereas the petrol engine compresses an air-fuel mixture. Half the students were not prepared for this and scored zero marks. Only about ten percent were able to give both basic differences. Although the question referred to engines rather than cycles, credit was given to those who compared the processes of heating (constant volume and constant pressure respectively) for ideal Otto and Diesel cycles.

In part **(b)(i)** only half the students were able to correctly place the spark in the petrol engine cycle. The most common incorrect answer was to place the spark at the highest pressure in the cycle. The mark scheme allowed for a generous possible range on the

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compression curve, up to top dead centre (t.d.c.), though slightly before t.d.c. was expected.

The calculation of work done in part **(b)(ii)** was generally done well, and it is evident that students are used to estimating the cycle area, usually by counting squares. We allowed a generous tolerance of ± one and a half 'large' squares, even so some gave answers outside this tolerance and lost a mark. It always helps the examiners if they can see the way students have found the area by drawing or shading (on Figure 1 in this case), especially as some count a mixture of large and small squares, and some use strips.
Far fewer were able to calculate the power, even though the formula was on the Formulae and Data sheet. Answers failed to include one or more of the following factors:

- one half (for one complete cycle every two revolutions)
- four (the number of cylinders)
- 1/60 (to convert to revolutions per second).

Some erroneously included π or 2π in their working.

Part **(b)(iii)** was generally answered successfully, with a carried error given for using the answer to **(b)(ii)**, unless it gave an efficiency greater than 100 per cent.

Part **(c)** was successfully answered by the majority of students, showing they had a good idea of the processes taking place in an Otto cycle.

Q12.

This type of question in (a) (where students were asked to make a choice from four options) was a departure from previous papers. About one third of all students gave the correct answer.
Part (b)(i) was answered well, with three-quarters of students scoring the two marks. Those who lost marks either put incorrect values in $p_1V_1 / T_1 = p_2V_2 / T_2$, or thought pressure or volume remained constant. The question clearly asked for the temperature at point B on Figure 3, but those who used the pressure in the air tank (4.5×10^5 Pa) instead of the pressure in the cylinder (4.6×10^5 Pa) were not penalised.

Students are quite used to calculating the area enclosed by a $p-V$ loop, and over half the students scored the full three marks in part (b)(ii). We allowed a generous tolerance of ± one ‘large’ square (=25 small squares), even so some gave answers outside this tolerance and lost a mark. It always helps the examiners if they can see the way students have found the area by drawing or shading (on Figure 3 in this case), especially as some count a mixture of large and small squares, and some use strips. A small proportion made errors in converting the area into joules. Some calculated the area under one or more of the separate processes rather than the area enclosed by the loop.

Students should beware of diving into the Formulae and Data Booklet without thinking carefully beforehand! All students needed to do in part (b)(iii) was multiply the work done per cycle (answer to part (b)(ii) with carried error if incorrect) by the number of cycles per second (7) but many went on to lose the mark because they used the formula for a four -stroke engine and multiplied again by a factor of one half.

Questions on cycles shown on a $p-V$ diagram have usually been set in contexts where there is a net output of work. In part (b)(iv) students were asked about a compressor cycle where there is a net *input* of work. Marking allowed for the fact that student’s knowledge of compressors is likely to be limited. Those students who had read the passage carefully were able to make a reasonable forecast of how the $p - V$ diagram would change even if it was only to say that BC would be at a higher pressure and that the area enclosed by the loop would be larger. They could also see what would happen to the work done, power and temperature as the air tank pressure increased. The best answers gave reasons for some or all of these changes. There were some very competent answers concerning the

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part played by the flywheel in smoothing the motion of a reciprocating machine, and more students now are familiar with the term ‘dead centre’ and use appropriate vocabulary e.g. ‘torque’ rather than ‘force’.

Q13.

Part (a) was a straightforward substitution into the formula for maximum theoretical efficiency, but it was frustrating to see that in about half the answers the temperatures were not converted to kelvin.

The mark was awarded for part (b) if students had divided 48 MW by their answer to part (a), even if they had not used kelvin temperatures. Once again, many felt they needed a prop and looked at the data sheet and used *efficiency* = *Q*in − *Q*out / *Q*in, wrongly thinking that *Q*out was the work output.

There have been questions set in the past where students have been asked to give reasons for inefficiencies, and the mark schemes and examiner’s reports have described the sort of answers that will score marks. Despite this, in part (c) there were far too many vague answers in terms of ‘heat loss to surroundings’ or ‘friction in the machinery’. The examiners were looking for some evidence that students had read the description of the power station and could fathom out where the major losses were. Answers concerning friction had to state where frictional energy loss occurred e.g. in bearings or between moving parts / surfaces. Only about one in ten students scored the full two marks.

Q14.

(a) (i) There was a significant number of candidates who attempted this part by using W = PΔV or W = PV. They made statements that because the two work values were the same then there was no change in the internal energy. Other candidates thought that PV = temperature.

Only the higher achieving candidates were able to produce convincing work that was correct and well-laid out with due regard to the fact that this was a “Show that...” style question.

(ii) The application of the first law of thermodynamics to the adiabatic expansion was well understood and effectively communicated by most candidates. Some candidates were unaware that this expansion was adiabatic and neglected to address this in their explanation.

(iii) Over 50% of candidates achieved all 3 marks in this part. However, in many cases the working was unconvincing with candidates opting for $\frac{P_A V_A}{P_C P_C}$ without any supporting workings. A few candidates did not realise that $\frac{T_A}{T_C}$ should have been

expressed as a decimal fraction in keeping with standard procedure for numerical answers.

(b) Many candidates attempted to use an approximation using W = P_{mean} × ΔV. This was equivalent to approximating the area under the curve to that of a trapezium. Such approaches were acceptable for 1 mark but required a statement identifying the answer as an over-estimate in order to access both marks.

The usual method for estimating an area was not seen as often as expected and

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even when seen it was done in an unconvincing manner. Again, with a “Show that...” style question working had to be clearly communicated; many candidates were unable to do this effectively and consequently dropped marks.

(c) Just under half of the candidates were able to deal with this multi-stage calculation and obtain all 3 marks. A common error was for candidates to convert the temperature increase of 18 °C to 291 K and substituting this value into Q = $mc\Delta\theta$. Other common mistakes were an inability to deal with the per-second aspect of the question and also quoting or rearranging $\rho = \frac{m}{v}$ incorrectly.

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