Please write clearly in block capitals.

Centre number	3	6	9	9	9	Candidate number	5	9	5	7

Surname Matheson

Forename(s) Lewis

Candidate signature

I declare this is my own work.

A-level
PHYSICS

Paper 3
Section B Engineering physics

A Level Physics Online . com

Thursday 15 June 2023 Morning

Time allowed: The total time for both sections of this paper is 2 hours. You are advised to spend approximately 50 minutes on this section.

Materials

For this paper you must have:

- a pencil and a ruler
- a scientific calculator
- a Data and Formulae Booklet
- a protractor.

Instructions

- Use black ink or black ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- If you need extra space for your answer(s), use the lined pages at the end of this book. Write the question number against your answer(s).
- Do all rough work in this book. Cross through any work you do not want to be marked.
- Show all your working.

For Examiner's Use	
Question	Mark
1	
2	
3	
4	
5	
TOTAL	

Information

- The marks for questions are shown in brackets.
- The maximum mark for this paper is 35.
- You are expected to use a scientific calculator where appropriate.
- A Data and Formulae Booklet is provided as a loose insert.

IB/M/Jun23/E7

Section B

Answer **all** questions in this section.

0 1 . 1 One equation used in translational dynamics is:

force = mass × acceleration

State **in words** the equivalent equation used in rotational dynamics.

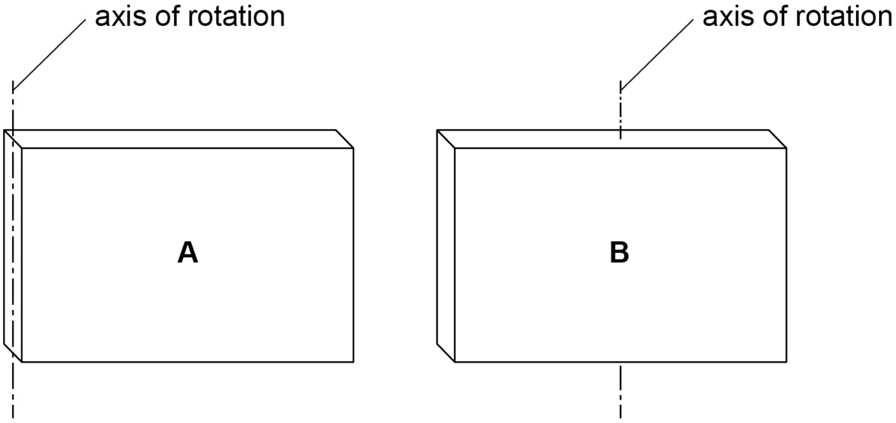
[2 marks]

torque = moment of inertia x angular acceleration

✓✓

Figure 1 shows two identical uniform plates **A** and **B**. The axis of rotation of each plate is shown.

Figure 1



0 1 . 2 State and explain which plate has the greater moment of inertia about its axis of rotation.

[2 marks]

$I = \Sigma mr^2$ ✓ ∴ A has a greater moment of inertia, because more of its mass is distributed at a greater distance from its axis of rotation. ✓

An electric motor drives a machine that punches out plates from a long strip of sheet metal. The motor runs continuously and is fitted with a flywheel. **Figure 2** shows how the angular velocity ω of the flywheel varies with time t.

Figure 2

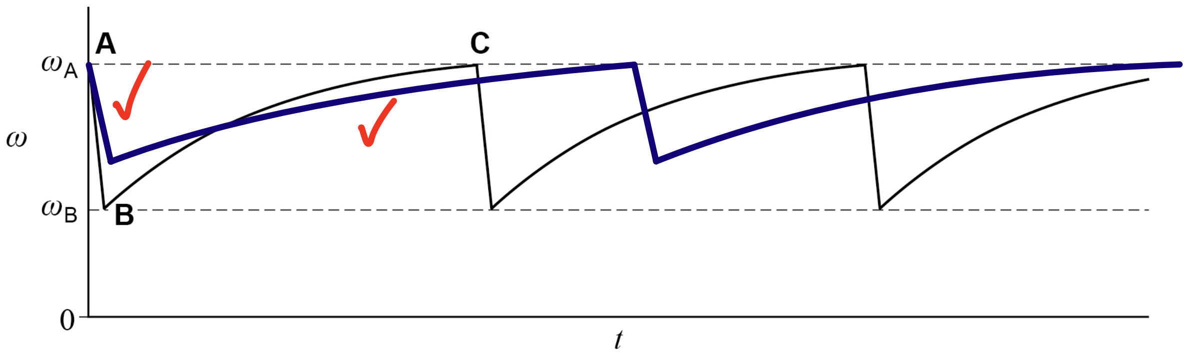


Table 1 describes the sequence for the machine after it has been brought up to speed ω_A.

Table 1

A	The punching operation starts.
A to **B**	The flywheel transfers some of its energy during the punching operation.
B to **C**	The flywheel is again brought up to speed ω_A by the motor.
C	The next punching operation starts.

0 1 . 3 A new flywheel with a greater moment of inertia is fitted in place of the original flywheel. The motor torque is constant and the same as before.

Sketch on **Figure 2** a graph showing how the angular velocity varies with time for the machine fitted with the new flywheel.

Assume that:

- the punching operation starts at the same angular speed ω_A
- the same quantity of energy is transferred when punching the metal sheet.

[2 marks]

Decrease in speed from ω_A is not as great because moment of inertia has increased, but takes longer to increase for the same reason $\therefore$ gradient is less steep.

Question 1 continues on the next page

0 1 . 4 Explain **one** difference between your graph and the original graph.

[1 mark]

For the same transfer of energy, new ω_B will be greater for a greater I. ✓

$\Delta E = \frac{1}{2} I (\omega_A^2 - \omega_B^2)$

$\Delta E =$ constant $I \uparrow$ ∴ $(\omega_A^2 - \omega_B^2) \downarrow$

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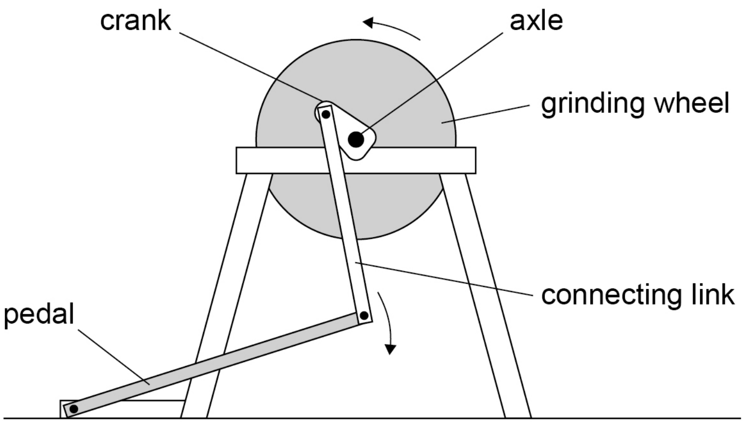
0 2 **Figure 3** shows a heavy stone grinding wheel used for sharpening tools.

Figure 3



The pedal is connected to the axle of the wheel by a connecting link and crank. The operator pushes the pedal downwards to accelerate the wheel from rest. The wheel begins to rotate in the direction shown.

0 2 . 1 Explain why the torque applied to the axle varies as the operator pushes downwards on the pedal.

[2 marks]

$T = Fr$, where r is the perpendicular distance between the axis of rotation and line of action of the force✓. In this case the line of action acts through the connecting link, which varies its position relative to the axle during a cycle.✓

Question 2 continues on the next page

Turn over ►

0 2 . 2 The wheel is rotating at a high angular speed. The operator is told not to use the pedal to stop the rotation of the wheel suddenly.

Explain, with reference to angular impulse, why a sudden stop is likely to damage the mechanism.

[2 marks]

$$T = Fr = mar = m\alpha r^2 = mr^2\frac{\Delta\omega}{t} = \Delta\left(I\frac{\omega}{t}\right)$$

$$T\Delta t = \Delta(I\omega)$$ ✓

If ω reduced to zero in a short time, then torque is really high. ✓

0 2 . 3 The connecting link breaks. At this instant the angular speed of the wheel is $13.8\ \text{rad s}^{-1}$.
It takes $15.0\ \text{s}$ for the wheel to come to rest.
The frictional torque acting at the axle bearings is $0.77\ \text{N m}$ and is constant for all speeds.

Calculate the moment of inertia of the wheel.

[2 marks]

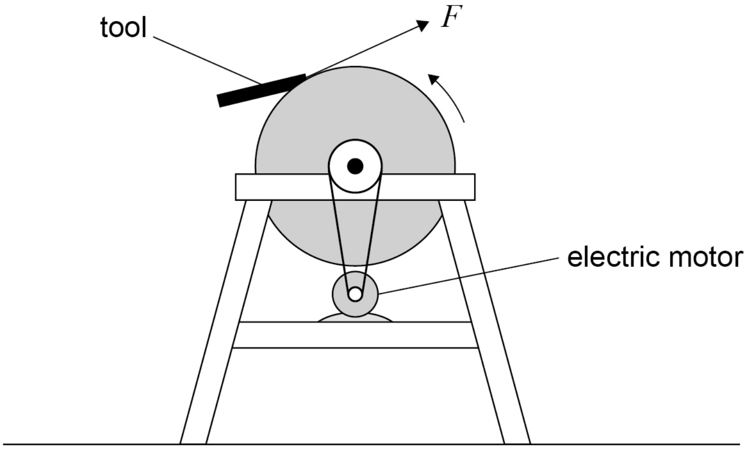
$$\alpha = \frac{\Delta\omega}{\Delta t} = \frac{13.8}{15.0} = 0.92\ \text{rad s}^{-2}$$ ✓

$$T = I\alpha \qquad I = \frac{T}{\alpha} = \frac{0.77}{0.92} = 0.837$$

moment of inertia = 0.84 ✓ kg m^2

The arrangement is modified as shown in **Figure 4**. The pedal, connecting link and crank are removed and the grinding wheel is driven by an electric motor.

Figure 4



0 2 . 4 **Figure 4** also shows a tool being sharpened by pressing it on the edge of the rotating wheel.
The tool applies a tangential force F on the wheel.
A torque of $3.10\ \text{N m}$ is needed at the axle to drive the wheel at constant angular speed while the tool is being sharpened.

frictional torque at the axle bearings $= 0.77\ \text{N m}$
radius of wheel $= 0.24\ \text{m}$

Calculate F.

[2 marks]

$T = T_{friction} + T_{tool}$

$T_{tool} = 3.1 - 0.77 = 2.33\ \text{Nm}$ ✓

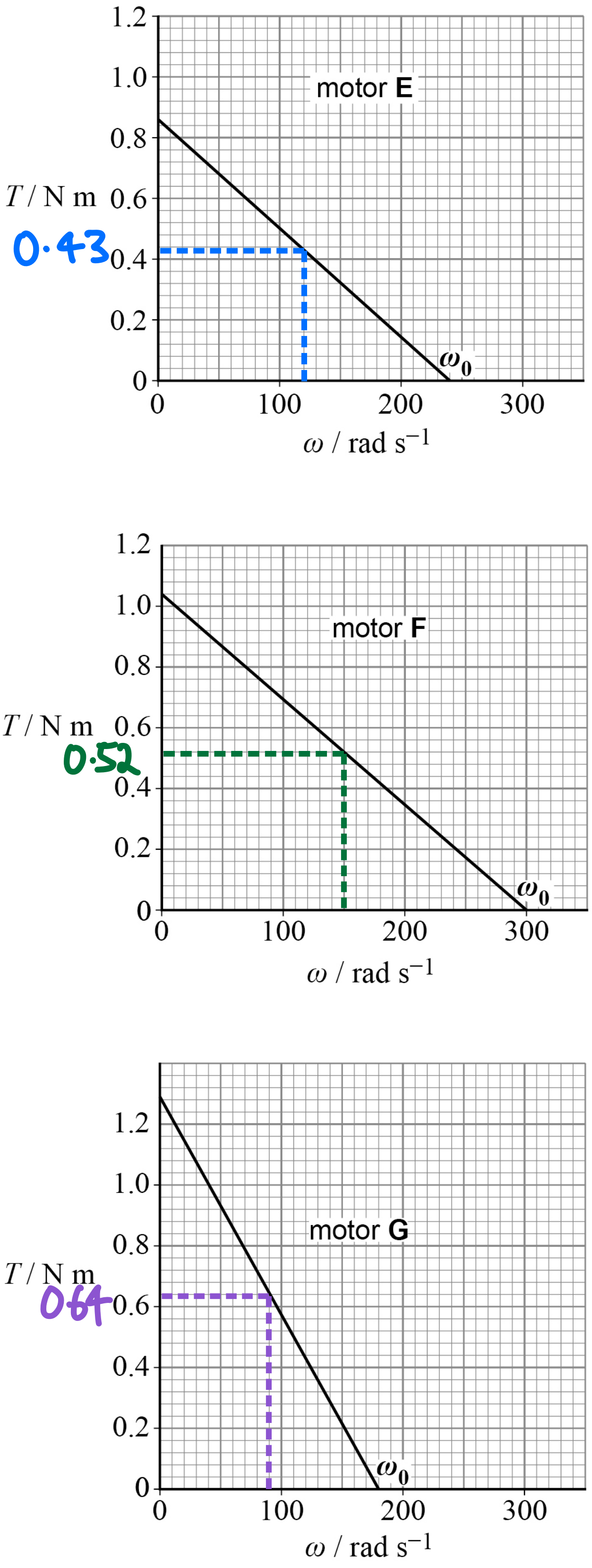
$T_{tool} = F_{tool} \times r$ $F_{tool} = 2.33/0.24 = 9.71$

$F =$ 9.7 ✓ N

Question 2 continues on the next page

0 2 . 5 Three motors **E**, **F** and **G** were available to drive the wheel in **Figure 4**.
Figure 5 shows how the torque T varies with angular speed ω for each motor.

Figure 5



The no-load speed ω_0 is the angular speed of a motor when the torque applied is zero.

The maximum power of each motor is developed at about $0.5\omega_0$.

The required output power of the motor when a tool is being sharpened is 52 W.

The required output power of the chosen motor should be about $\frac{2}{3}$ of its maximum power.

Deduce which motor **E**, **F** or **G** was chosen for this application.

[3 marks]

$P = T\omega$

$P = T \times 0.5\omega_0 \times 2/3$ ✓

E: $P = 0.43 \times 0.5 \times 240 \times \frac{2}{3} = 35\text{ W}$

F: $P = 0.52 \times 0.5 \times 300 \times \frac{2}{3} = 52\text{ W}$ ✓

G: $P = 0.64 \times 0.5 \times 180 \times \frac{2}{3} = 39\text{ W}$

Motor F is the only motor suitable for this application. ✓

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Turn over for the next question

0 3 . 1 The first law of thermodynamics can be written as:

$$Q = \Delta U + W$$

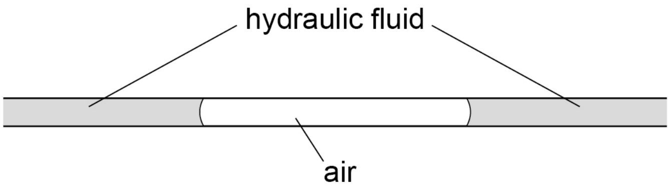
State what Q represents in this equation.

[1 mark]

Energy transferred to the system by heating. ✓

Air in the brake pipe of a bicycle hydraulic brake system can be dangerous.
Figure 6 shows a bubble of air in a brake pipe.

Figure 6



Assume that the hydraulic fluid is incompressible.
During a sudden application of the brake, the air is compressed adiabatically to a high pressure.

0 3 . 2 The work done on the air when it is compressed is 10.8 mJ.

Which row is correct for this adiabatic compression?

$Q=0 \quad \therefore W = -U$

Tick (✓) **one** box.

[1 mark]

W / mJ	Q / mJ	ΔU / mJ	
−10.8	0	10.8	✓ ✓
~~10.8~~	~~10.8~~	~~0~~	☐
−10.8	−~~10.8~~	~~0~~	☐
~~10.8~~	0	−~~10.8~~	☐

W is -ve as work is done on the gas, not by the gas. U increases ∴ ΔU is +ve.

0 3 . 3 The initial conditions for the air are:

volume of air = 2.91×10^{-8} m^3
pressure of air = 1.05×10^5 Pa
temperature of air = 293 K.

During sudden braking, the air in the bubble is compressed adiabatically to a volume of 3.19×10^{-9} m^3.

Calculate the pressure and the temperature of the air immediately after the compression.

γ for air = 1.4

[3 marks]

$$p_1 V_1^{\propto} = p_2 V_2^{\propto} \checkmark$$

$$p_2 = p_1 \left(\frac{V_1}{V_2}\right)^{\propto} = 1.05 \times 10^5 \times \left(\frac{2.91 \times 10^{-8}}{3.19 \times 10^{-9}}\right)^{1.4}$$

$$p_2 = 2.3192 \times 10^6 \text{ Pa}$$

$$\frac{pV}{T} = k \qquad \frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$T_2 = T_1 \frac{p_2 V_2}{p_1 V_1} = 293 \times \frac{2.3192 \times 10^6 \times 3.19 \times 10^{-9}}{1.05 \times 10^5 \times 2.91 \times 10^{-8}}$$

pressure = 2.32×10^6 ✓ Pa

temperature = 709 ✓ K

Question 3 continues on the next page

0 3 . 4 To produce the adiabatic change, the brake lever is pulled very quickly.
The cyclist thinks that by applying the brake slowly, the work done to compress the bubble to a volume of 3.19×10^{-9} m^3 will be greater than 10.8 mJ.

Deduce without calculation whether the cyclist is correct.

[2 marks]

Applying the brake slowly means the internal energy stays constant due to energy loss by heat transfer ✓ ∴ work done would be lower because pressure is lower ✓
∴ the cyclist is incorrect.

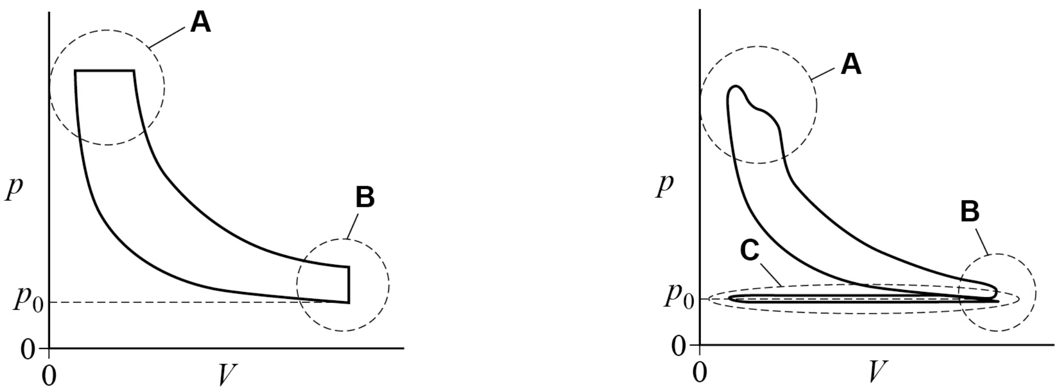
7

Turn over for the next question

Turn over ►

0 4 **Figure 7** shows the p–V diagram for a theoretical diesel engine cycle.
Figure 8 shows the indicator diagram for a real four-stroke diesel engine working between the same maximum and minimum volumes.

Figure 7 **Figure 8**



p_0 is atmospheric pressure.

Compare the indicator diagram with the theoretical diesel cycle.
In your answer, explain:

- the differences between region **A** on **Figure 7** and region **A** on **Figure 8**
- the differences between region **B** on **Figure 7** and region **B** on **Figure 8**
- why the features shown in region **C** appear only on the indicator diagram
- why the efficiency of the real engine will always be less than the efficiency predicted by an analysis of the theoretical cycle.

[6 marks]

A: Heating cannot occur at constant pressure as heating cannot be controlled and max pressure is lower in a real engine. ✓

B: Corners are rounded at B on real cycle as valves take a finite time to open/close. Cooling cannot occur at constant volume as piston takes finite time to cool/stop. ✓✓

C: Real engine needs an induction (lower) and exhaust (upper) stroke, whereas in a theoretical cycle air is repeatedly used. ✓

Efficiency: Area of loop is smaller for real cycles ∴ less work done per cycle. Area of pumping loop needs to be subtracted from the main loop. Some energy is also needed to pump oil and coolant through the engine. Expansion and compression are not adiabatic and the fuel is not completely burnt. These all cause the efficiency to be lower. ✓✓

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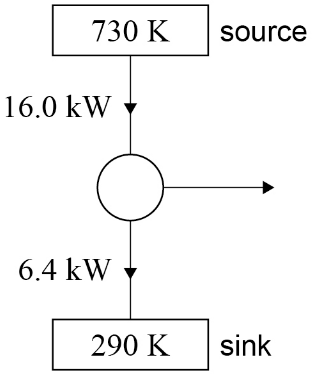
0 5 **Figure 9** shows an ideal heat engine.

Figure 9



The engine operates between a source at a temperature of 730 K and a sink at a temperature of 290 K.
The input power is 16.0 kW and the power rejected to the sink is 6.4 kW.

0 5 . 1 Calculate the efficiency of this engine.

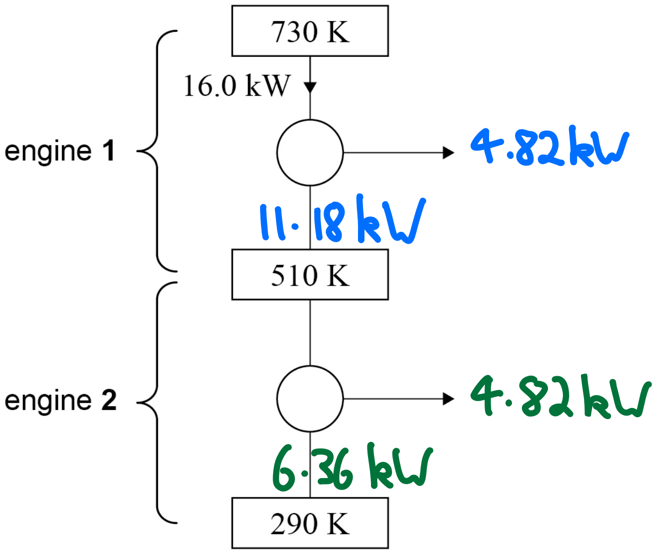
[1 mark]

$$\eta = \frac{T_H - T_C}{T_H} = \frac{730-290}{730} = 0.603$$

efficiency = 0.60 ✓

0 5 . 2 **Figure 10** shows another system operating between the same overall temperatures and with the same input power as the engine in **Figure 9**. This system consists of two ideal engines.

Figure 10



The sink for engine **1** forms the source for engine **2**. The temperature of the intermediate reservoir is 510 K.
All the energy rejected by heat transfer in engine **1** provides the input energy to engine **2**.
A student suggests that the system in **Figure 10** can provide more output power and be more efficient than the engine in **Figure 9**.

Deduce whether the student's suggestions are correct.
You may annotate **Figures 9** and **10**.

[3 marks]

Engine 1: $\eta_1 = \frac{730-510}{730} = 0.301$ ∴ $P_{out} = 0.301 \times 16.0$

$P_{1out} = 4.82$ kW

$Q_{1c} = 16.0 - 4.82 = 11.18$ kW ✓

Engine 2: $\eta_2 = \frac{510-290}{290} = 0.431$ ∴ $P_{out} = 0.431 \times 11.18$

$P_{2out} = 4.82$ kW

$Q_{2c} = 11.18 - 4.82 = 6.36$ kW ✓

Total output $= P_1 + P_2 = 4.82 + 4.82 = 9.64$ kW

Total $\eta = 9.64/16.0 = 0.603$

END OF QUESTIONS

Both power and efficiency are the same for the 2 figures ∴ they are not correct. ✓

4

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ANSWER IN THE SPACES PROVIDED

Question number	**Additional page, if required.** **Write the question numbers in the left-hand margin.**

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