

Surname		Other Names	
Centre Number		Candidate Number	
Candidate Signature			

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General Certificate of Education
June 2004
Advanced Subsidiary Examination



PHYSICS (SPECIFICATION A) PHA3/W
Unit 3 Current Electricity and Elastic Properties of Solids

Monday 14 June 2004 Afternoon Session

<p>In addition to this paper you will require:</p> <ul style="list-style-type: none"> • a calculator; • a pencil and a ruler.

For Examiner's Use			
Number	Mark	Number	Mark
1			
2			
3			
4			
5			
6			
Total (Column 1)	→		
Total (Column 2)	→		
TOTAL			
Examiner's Initials			

Time allowed: 1 hour

Instructions

- Use blue or black ink or ball-point pen.
- Fill in the boxes at the top of this page.
- Answer **all** questions in the spaces provided. All working must be shown.
- Do all rough work in this book. Cross through any work you do not want marked.

Information

- The maximum mark for this paper is 50.
- Mark allocations are shown in brackets.
- The paper carries 25% of the total marks for Physics Advanced Subsidiary and carries 12 ½% of the total marks for Physics Advanced.
- A *Data Sheet* is provided on pages 3 and 4. You may wish to detach this perforated sheet at the start of the examination.
- You are expected to use a calculator where appropriate.
- In questions requiring description and explanation you will be assessed on your ability to use an appropriate form and style of writing, to organise relevant information clearly and coherently, and to use specialist vocabulary where appropriate. The degree of legibility of your handwriting and the level of accuracy of your spelling, punctuation and grammar will also be taken into account.

Data Sheet

- A perforated Data Sheet is provided as pages 3 and 4 of this question paper.
- This sheet may be useful for answering some of the questions in the examination.
- You may wish to detach this sheet before you begin work.

Fundamental constants and values			
Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^8	m s^{-1}
permeability of free space	μ_0	$4\pi \times 10^{-7}$	H m^{-1}
permittivity of free space	ϵ_0	8.85×10^{-12}	F m^{-1}
charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\text{N m}^2 \text{kg}^{-2}$
the Avogadro constant	N_A	6.02×10^{23}	mol^{-1}
molar gas constant	R	8.31	$\text{J K}^{-1} \text{mol}^{-1}$
the Boltzmann constant	k	1.38×10^{-23}	J K^{-1}
the Stefan constant	σ	5.67×10^{-8}	$\text{W m}^{-2} \text{K}^{-4}$
the Wien constant	a	2.90×10^{-3}	m K
electron rest mass	m_e	9.11×10^{-31}	kg
(equivalent to $5.5 \times 10^{-4}u$)			
electron charge/mass ratio	em_e	1.76×10^{11}	C kg^{-1}
proton rest mass	m_p	1.67×10^{-27}	kg
(equivalent to 1.00728u)			
proton charge/mass ratio	em_p	9.58×10^7	C kg^{-1}
neutron rest mass	m_n	1.67×10^{-27}	kg
(equivalent to 1.00867u)			
gravitational field strength	g	9.81	N kg^{-1}
acceleration due to gravity	g	9.81	m s^{-2}
atomic mass unit	u	1.661×10^{-27}	kg
(1u is equivalent to 931.3 MeV)			
Fundamental particles			
Class	Name	Symbol	Rest energy /MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	e^\pm	0.510999
mesons	muon	μ^\pm	105.659
	pion	π^\pm	139.576
		π^0	134.972
	kaon	K^\pm	493.821
baryons		K^0	497.762
	proton	p	938.257
	neutron	n	939.551
Properties of quarks			
Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}$	$+\frac{1}{3}$	-1
Geometrical equations			
arc length = $r\theta$			
circumference of circle = $2\pi r$			
area of circle = πr^2			
area of cylinder = $2\pi rh$			
volume of cylinder = $\pi r^2 h$			
area of sphere = $4\pi r^2$			
volume of sphere = $\frac{4}{3}\pi r^3$			

Mechanics and Applied Physics
$v = u + at$
$s = \left(\frac{u+v}{2}\right)t$
$s = ut + \frac{at^2}{2}$
$v^2 = u^2 + 2as$
$F = \frac{\Delta(mv)}{\Delta t}$
$P = Fv$
efficiency = $\frac{\text{power output}}{\text{power input}}$
$\omega = \frac{v}{r} = 2\pi f$
$a = \frac{v^2}{r} = r\omega^2$
$I = \sum mr^2$
$E_k = \frac{1}{2}I\omega^2$
$\omega_2 = \omega_1 + at$
$\theta = \omega_1 t + \frac{1}{2}at^2$
$\omega_2^2 = \omega_1^2 + 2\alpha\theta$
$\theta = \frac{1}{2}(\omega_1 + \omega_2)t$
$T = I\alpha$
angular momentum = $I\omega$
$W = T\theta$
$P = T\omega$
angular impulse = change of angular momentum = Tt
$\Delta Q = \Delta U + \Delta W$
$\Delta W = p\Delta V$
$pV^\gamma = \text{constant}$
work done per cycle = area of loop
input power = calorific value \times fuel flow rate
indicated power as (area of $p - V$ loop) \times (no. of cycles/s) \times (no. of cylinders)
friction power = indicated power - brake power
efficiency = $\frac{W}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}}$
maximum possible efficiency = $\frac{T_H - T_C}{T_H}$

Fields, Waves, Quantum Phenomena
$g = \frac{F}{m}$
$g = -\frac{GM}{r^2}$
$g = -\frac{\Delta V}{\Delta x}$
$V = -\frac{GM}{r}$
$a = -(2\pi f)^2 x$
$v = \pm 2\pi f \sqrt{A^2 - x^2}$
$x = A \cos 2\pi ft$
$T = 2\pi \sqrt{\frac{m}{k}}$
$T = 2\pi \sqrt{\frac{l}{g}}$
$\lambda = \frac{\omega S}{D}$
$d \sin \theta = n\lambda$
$\theta \approx \frac{\lambda}{D}$
$n_2 = \frac{\sin \theta_1}{\sin \theta_2} = \frac{c_1}{c_2}$
$n_2 = \frac{n_1}{n_2}$
$\sin \theta_c = \frac{1}{n}$
$E = hf$
$hf = \phi + E_k$
$hf = E_1 - E_2$
$\lambda = \frac{h}{p} = \frac{h}{mv}$
$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$
Electricity
$\epsilon = \frac{E}{Q}$
$\epsilon = I(R + r)$
$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
$R_T = R_1 + R_2 + R_3 + \dots$
$P = I^2 R$
$E = \frac{F}{Q} = \frac{V}{d}$
$E = \frac{1}{4\pi \epsilon_0} \frac{Q}{r^2}$
$E = \frac{1}{2} QV$
$F = BIl$
$F = BQv$
$Q = Q_0 e^{-t/RC}$
$\Phi = BA$

$$\text{magnitude of induced e.m.f.} = N \frac{\Delta\Phi}{\Delta t}$$

$$I_{\text{rms}} = \frac{I_0}{\sqrt{2}}$$

$$V_{\text{rms}} = \frac{V_0}{\sqrt{2}}$$

Mechanical and Thermal Properties

$$\text{the Young modulus} = \frac{\text{tensile stress}}{\text{tensile strain}} = \frac{F}{A} \frac{l}{e}$$

$$\text{energy stored} = \frac{1}{2} Fe$$

$$\Delta Q = mc \Delta\theta$$

$$\Delta Q = ml$$

$$pV = \frac{1}{3} Nmc^2$$

$$\frac{1}{2} mc^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$$

Nuclear Physics and Turning Points in Physics

$$\text{force} = \frac{eV_p}{d}$$

$$\text{force} = Bev$$

$$\text{radius of curvature} = \frac{mv}{Be}$$

$$\frac{eV}{d} = mg$$

$$\text{work done} = eV$$

$$F = 6\pi\eta rv$$

$$I = k \frac{I_0}{x^2}$$

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$\lambda = \frac{h}{\sqrt{2meV}}$$

$$N = N_0 e^{-\lambda t}$$

$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

$$R = r_0 A^{\frac{1}{3}}$$

$$E = mc^2 = \frac{m_0 c^2}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

$$l = l_0 \left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}$$

$$t = \frac{t_0}{\left(1 - \frac{v^2}{c^2}\right)^{\frac{1}{2}}}$$

Astrophysics and Medical Physics

Body	Mass/kg	Mean radius/m
Sun	2.00×10^{30}	7.00×10^8
Earth	6.00×10^{24}	6.40×10^6

1 astronomical unit = 1.50×10^{11} m

1 parsec = 206265 AU = 3.08×10^{16} m = 3.26 ly

1 light year = 9.45×10^{15} m

Hubble constant (H) = $65 \text{ km s}^{-1} \text{ Mpc}^{-1}$

$$M = \frac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$$

$$M = \frac{f_o}{f_e}$$

$$m - M = 5 \log \frac{d}{10}$$

$$\lambda_{\text{max}} T = \text{constant} = 0.0029 \text{ m K}$$

$$v = Hd$$

$$P = \sigma AT^4$$

$$\frac{\Delta f}{f} = \frac{v}{c}$$

$$\frac{\Delta \lambda}{\lambda} = -\frac{v}{c}$$

$$R_s \approx \frac{2GM}{c^2}$$

Medical Physics

$$\text{power} = \frac{1}{f}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \text{ and } m = \frac{v}{u}$$

$$\text{intensity level} = 10 \log \frac{I}{I_0}$$

$$I = I_0 e^{-\mu x}$$

$$\mu_m = \frac{\mu}{\rho}$$

Electronics

Resistors

Preferred values for resistors (E24)

Series: 1.0 1.1 1.2 1.3 1.5 1.6 1.8 2.0 2.2 2.4 2.7 3.0 3.3 3.6 3.9 4.3 4.7 5.1 5.6 6.2 6.8 7.5 8.2 9.1 ohms

and multiples that are ten times greater

$$Z = \frac{V_{\text{rms}}}{I_{\text{rms}}}$$

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$$

$$C_T = C_1 + C_2 + C_3 + \dots$$

$$X_C = \frac{1}{2\pi f C}$$

Alternating Currents

$$f = \frac{1}{T}$$

Operational amplifier

$$G = \frac{V_{\text{out}}}{V_{\text{in}}} \text{ voltage gain}$$

$$G = -\frac{R_f}{R_1} \text{ inverting}$$

$$G = 1 + \frac{R_f}{R_1} \text{ non-inverting}$$

$$V_{\text{out}} = -R_f \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right) \text{ summing}$$

Answer **all** questions in the spaces provided.

1 A battery is connected across a uniform conductor. The current in the conductor is 40 mA.

(i) Calculate the total charge that flows past a point in the conductor in 3 minutes.

.....
.....
.....

(ii) Using data from the Data Sheet calculate the number of electron charge carriers passing the same point in the conductor in this time.

.....
.....

(iii) If 8.6 J of energy are transferred to the conductor in this time, calculate the potential difference across the conductor.

.....
.....
.....

(iv) Calculate the resistance of the conductor.

.....
.....

(6 marks)

6

- 2 (a) **Figure 1** shows two possible arrangements of connecting three resistors, each resistor having a resistance of $40\ \Omega$.

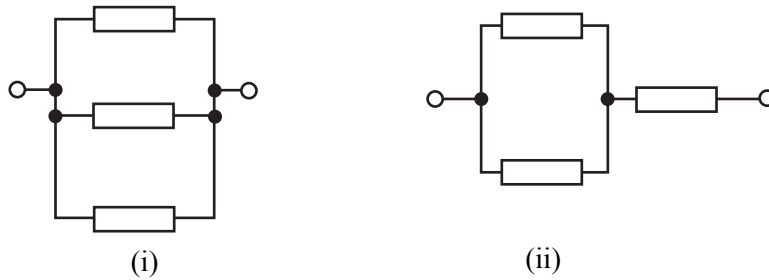


Figure 1

Calculate the equivalent resistance in each case.

- (i)
-
-
- (ii)
-
-

(3 marks)

- (b) The designer of a heating element for the rear window of a car decides to connect six separate heating elements together as shown in **Figure 2**. Each element has a resistance of $6.0\ \Omega$ and the unit is connected to a $12\ \text{V}$ dc supply having zero internal resistance.

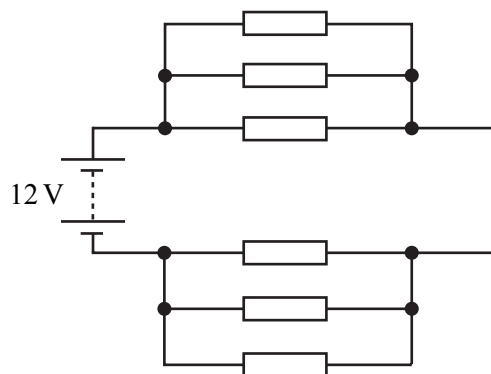


Figure 2

(i) Calculate the current in each single element.

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.....

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(ii) With the aid of a similar calculation give a reason why the heater would not be as effective if all six were connected in series.

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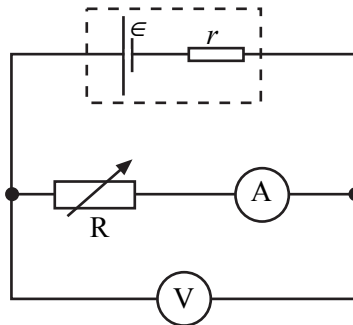
(5 marks)

8

TURN OVER FOR THE NEXT QUESTION

Turn over ▶

- 3 In the circuit shown, a battery of emf ϵ and internal resistance r is connected to a variable resistor R . The current I and the voltage V are read by the ammeter and voltmeter respectively.



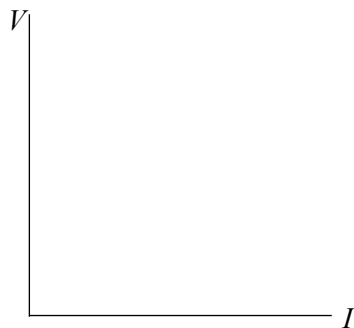
- (a) The emf is related to V , I and r by the equation

$$\epsilon = V + Ir.$$

Rearrange the equation to give V in terms of ϵ , I and r .

.....
(1 mark)

- (b) In an experiment, the value of R is altered so that a series of values of V and the corresponding values of I are obtained. Using the axes, sketch the graph you would expect to obtain as R is changed.



(2 marks)

- (c) State how the values of ϵ and r may be obtained from the graph.

ϵ

r

(2 marks)

- 4 (a) Give an expression for the *resistivity* of a material in the form of a uniform wire. Define all the symbols used.

.....

.....

.....

(2 marks)

- (b) A thin film of carbon may be used in some electronic systems. Typical dimensions of such a film are shown in **Figure 3**.

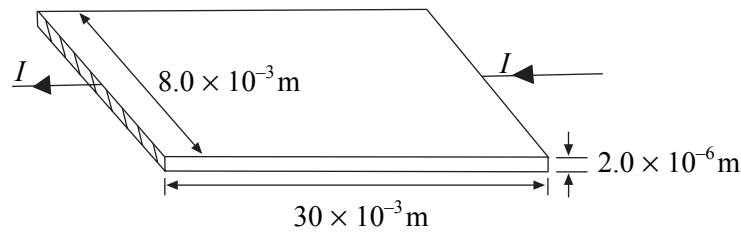


Figure 3

- (i) Calculate the resistance of the carbon film to a current I passing through it as shown in **Figure 3**.

resistivity of carbon = $4.0 \times 10^{-5} \Omega \text{ m}$

.....

.....

- (ii) Without recalculating the resistance of the carbon film, explain how you would expect the resistance to change if the current flowed as in **Figure 4**. You should consider the numerical ratio or factor by which each dimension affecting the resistance has changed.

You may be awarded marks for the quality of written communication in your answer.

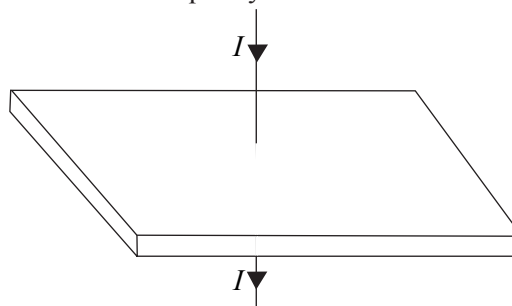


Figure 4

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(4 marks)

Turn over ▶

- 5 The circuit in **Figure 5** has a thermistor connected in series to a $200\ \Omega$ resistor and a $12\ \text{V}$ battery of negligible internal resistance. **Figure 6** shows how the resistance, R_{th} , of the thermistor varies with temperature.

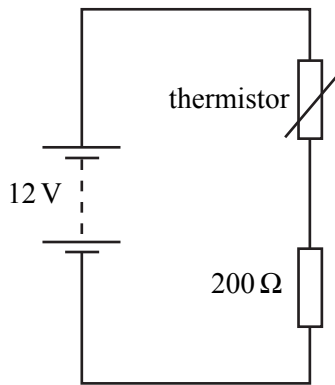


Figure 5

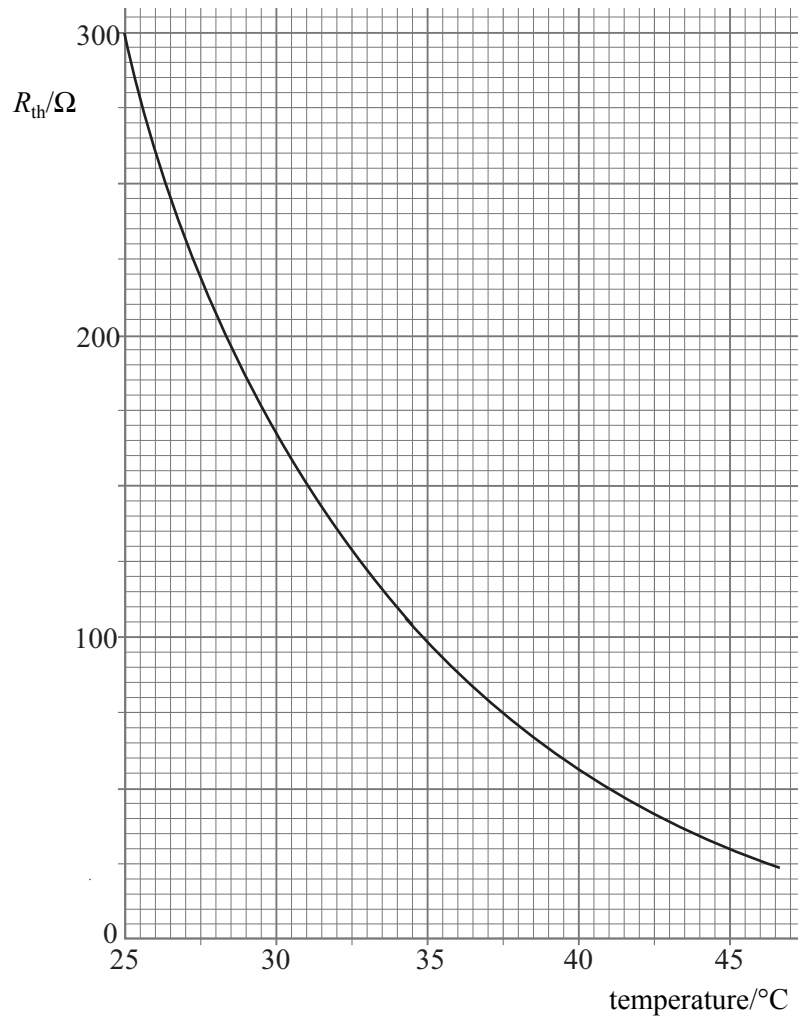


Figure 6

- (a) (i) Calculate the current in the circuit when the temperature is $25\ ^{\circ}\text{C}$.

.....

.....

.....

- (ii) Calculate the potential difference across the thermistor at $25\ ^{\circ}\text{C}$.

.....

.....

(3 marks)

- (b) Without further calculation, explain how you would expect the potential difference across the thermistor to change as the temperature increases from 25 °C.

You may be awarded marks for the quality of written communication in your answer.

.....

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(3 marks)

- (c) The circuit in **Figure 5** is modified by removing the 200 Ω resistance to give the circuit in **Figure 7**.

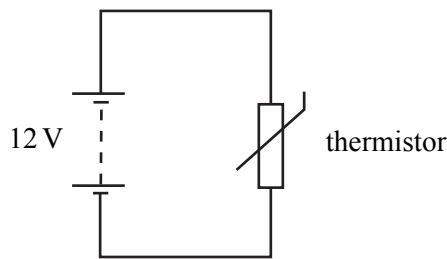


Figure 7

The temperature of the thermistor is increased at a steady rate from 25 °C to 45 °C in 10 minutes.

- (i) Calculate the power dissipated in the thermistor at
- 25 °C
-
- 45 °C

- (ii) Use the mean value of the powers determined in part (c)(i) to calculate the energy supplied by the battery during the period in which the temperature of the thermistor increases.

.....

.....

- (iii) State why the energy value, determined in part (c)(ii) is not an accurate value.

.....

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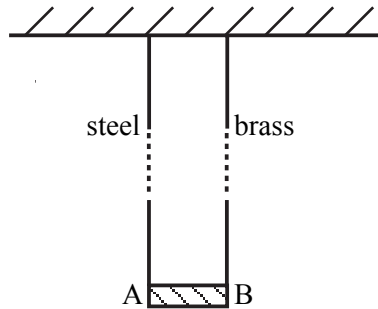
(6 marks)

- 6 (a) State *Hooke's law* for a material in the form of a wire.

.....

(2 marks)

- (b) A rigid bar AB of negligible mass, is suspended horizontally from two long, vertical wires as shown in the diagram. One wire is made of steel and the other of brass. The wires are fixed at their upper end to a rigid horizontal surface. Each wire is 2.5 m long but they have different cross-sectional areas.



When a mass of 16 kg is suspended from the centre of AB, the bar remains horizontal.

the Young modulus for steel = 2.0×10^{11} Pa
 the Young modulus for brass = 1.0×10^{11} Pa

- (i) What is the tension in each wire?

.....

- (ii) If the cross-sectional area of the steel wire is $2.8 \times 10^{-7} \text{ m}^2$, calculate the extension of the steel wire.

.....

- (iii) Calculate the cross-sectional area of the brass wire.

.....

- (iv) Calculate the energy stored in the steel wire.

.....

(7 marks)

(c) The brass wire is replaced by a steel wire of the same dimensions as the brass wire. The same mass is suspended from the midpoint of AB.

(i) Which end of the bar is lower?

.....

(ii) Calculate the vertical distance between the ends of the bar.

.....

.....

(2 marks)

QUALITY OF WRITTEN COMMUNICATION (2 marks)

END OF QUESTIONS

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