A-Level Physics

Rotational Kinetic Energy

Mark Scheme

Time available: 66 minutes
Marks available: 36 marks

1. (a) Equates initial E_p to linear E_k and rotational E_k ✓

Substitutes values and uses $V = r\omega$ ✓

Calculates V to give 0.51 m s^{-1} ✓

$9.2 \times 10^{-2} \times 9.81 \times 0.5 = (½ \times 9.2 \times 10^{-2}\, V^2) + (½ \times 8.6 \times 10^{-5} \times \frac{V^2}{0.005^2})$

$V = 0.51$ m s^{-1}

Some substitution of data must be seen for MP2

Do not allow MP3 for no consideration of linear E_k

Give 1 mark if $mgh = ½I\omega^2$ used with answer 0.51 m s^{-1}

3

(b) Calculates α from $\alpha = T/I$ ✓

Attempts to use any appropriate equation(s) of motion (for angular motion) ✓

Substitutes into equation(s) of motion and calculates θ ✓

$\alpha = (8.3 \times 10^{-4}) / 8.6 \times 10^{-5} = 9.65$ rad s^{-2} or 9.7 rad s^{-2}

$\theta = 145 \times 10 - ½ \times 9.7 \times 10^2 = 967$ rad or 970 rad

MP2: $\omega_2^2 = \omega_1^2 + 2\alpha\theta$ is not enough on its own as there are two unknowns.

MP2: Quoting appropriate formula(e) is not enough. There must be some attempt at substituting the data.

3

[6]

2. (a) 2.9 rev s^{-1} equivalent = $2\pi \times 2.9$ rad s^{-1} = 8.2 rad s^{-1}

OR $I = 2\,E_k / \omega^2$

OR correct substitution in $E_k = ½\, I\, \omega^2$ ✓

leading to $I = 6.2 \times 10^{-2}$ kg m^2 ✓

1st mark for correct conversion rev s^{-1} OR rearranging energy equation in terms of I OR correct substitution in $E_k = ½\, I\, \omega^2$

2nd mark for correct answer.

Do not allow final answer to 1 sig fig e.g. 0.06

2

(b) I depends on how mass is distributed about axis (of rotation)

For arms, screw and punch same mass is/point masses are closer to axis than the steel balls (making M of I lower) ✓

I depends on r^2 so I changes greatly for small change in in r ✓

Allow 'other parts' or 'other components' if it is clear this means screw, punch and arms

2

(c) $\alpha = \frac{2 \times \pi \times (0 - 2.9)}{0.089} = -205$ rad s^{-2} ✓

Attempt to use $\omega_2^2 = \omega_1^2 + 2\alpha\theta$ or $\theta = \omega 1t + ½ \alpha t^2$

or $\theta = ½ (\omega_1 + \omega_2)t$ ✓

giving $\theta = 0.81$ rad ✓

Condone missing sign or α given as positive Accept 200 rad s^{-2}

If α positive, 2nd mark for attempt to use

$\omega_2^2 = \omega_1^2 - 2\alpha\theta$ or $\theta = \omega_1 t - ½ \alpha t^2$

or $\theta = ½(\omega_1 + \omega_2)t$ ✓

ECF for value of ω used in (a)

3

(d) ($I = 2\, mr^2$ and $E_k = ½\, I\, \omega 2$)

Increasing y by 15% gives new $I = 1.15^2 \times$ original I (or 1.32) ✓

Increasing R by 15% increases I by 1.15^3 (or 1.52) ✓

Second option gives greater increase in I, and E_k also increased (by same ratio). ✓

Accept answers without calculation:

I prop to y^2 ✓

I prop to R^3 ✓

For <u>same</u> % increase in y or R, I and hence E_k increases more by increasing R ✓

Note: $E_k = m\, r^2\, \omega^2 = 4/3\, \pi\, R^3\, \rho\, r^2\, \omega^2$ for each ball

3

(e) ✓ against N m s

1

[11]

3. (a)

	Place a tick or ticks in this column
The moment of inertia will decrease	
The angular velocity will decrease	✓
The angular momentum will be unaltered	✓

1

(b) Flywheel acts as store of energy ✓

Able to deliver large amount of E_K in short time ✓

Without flywheel motor would stall during stamping (as load torque excessively high) ✓

max 2

(c) Converts rev min^{-1} to rad s^{-1}: 67.0 and 37.7 rad s^{-1} ✓

$E_K = \frac{1}{2} \times 25 \times (67.0^2 - 37.7^2) = 3.83 \times 10^4$ J ✓

2

(d) $\alpha = (\omega_2 - \omega_1)/t$

= (67.0 - 37.7)/5.0 = 5.86 rad s^{-2} ✓

$T = I\alpha$

= 25 × 5.86 = 147 ✓

If (67 - 0)/5.0 used, leading to T = 335 give 1 mark

Allow approach using angular displacement θ and

$\frac{\text{change in energy}}{\theta}$

2

(e) $P = \Delta E_K / t$ = 7.7 kW ✓

OR $P = T \times \omega_{AVE}$ = 147 × 52.4 = 7.7 kW ✓

Allow CE from 01.4

2

(f) For smaller speed variation, greater I required ✓

I proportional to $\rho t r^4$ $\quad (I = \frac{1}{2}\pi r^2 t \rho r^2)$ ✓

Shows that greatest $\rho t r^4$ is for flywheel B ✓ (hence B)

OR discusses qualitatively:

A has smaller r but compensated for by greater t and ρ (hence greater m) ✓

B has smaller mass because of low ρ and t but <u>much greater</u> r
r is squared twice ✓

$m_A = 498$ kg, $m_B = 228$ kg

i.e. m_A roughly $2 \times m_b$

but r_B^2 is roughly $3 \times r_A^2$

hence $I_B > I_A$

3

[12]

4. (a) (Gravitational potential energy of falling mass) is converted to linear/translational ke of mass and rotational ke of wheel ✓

1

and internal energy in bearings / air around wheel ✓

1

(b) (Use of $mgh = ½mv^2 + ½I\omega^2 + T\theta$)

$mgh = 2.94$ J

$(0.200 \times 9.81 \times 1.50) = (0.5 \times 0.200 \times 2.22^2) + (0.5 \times I \times 6.73^2)$

$½mv^2 = 0.493$ J

$+ (7.5 \times 10^{-3} \times 4.55)$

$T\theta = 0.0728$ J

E_P <u>or</u> E_K correct ✓

1

If friction torque not worked out out, give up to max 2 marks. Give full marks if friction torque worked out and stated as negligible.

All E_P, E_K and $T\theta$ correct ✓

1

Leading to $I = 2.41(3) / 22.6$ ✓ ($= 0.107$ kg m^2)

Gives

$I = 0.108$ kg m^2

1

(c) $\alpha = T / I = 7.5 \times 10^{-3} / 0.107 = 0.0701$ rad s^{-2} ✓

1

substitution of $\omega_2 = 0$, $\omega_1 = 6.73$ and α into $\omega_2^2 = \omega_1^2 - 2\alpha\theta$

leading to $\theta = 323$ rad ✓

OR

$\frac{1}{2}I\omega^2 = T\theta$ $0.5 \times 0.107 \times 6.73^2 = 7.5 \times 10^{-3}\ \theta$ ✓

$\theta = 323$ rad ✓

Give CE if

$I = 0.108$ kg m^2 used

1

[7]