Work, energy and power: practice worksheet

IB Physics HL · A.3 · 48 minutes · 40 marks

Question 1

A crate moves horizontally along a level floor. A rope pulls the crate with a constant force.

Data:

Pulling force: 36.0 N

Angle of rope above the horizontal: 35.0°

Horizontal displacement: 4.50 m

(a) Calculate the work done by the pulling force. [2]

(b) State the work done by the normal reaction on the crate. [1]

Question 2

A laboratory slider moves along a horizontal guide. Its mass remains constant.

Data:

Mass: 0.800 kg

Initial momentum magnitude: 12.0 kg m s^{-1}

Net work subsequently done on the slider: +70.0 J

(a) Determine the initial kinetic energy of the slider. [2]

(b) Hence determine the final speed of the slider. [2]

Question 3

A trolley of mass 2.40 kg starts from rest at displacement $s = 0$. The resultant force is parallel to its displacement. A force–displacement graph consists of straight lines joining the following points in order:

s / m	0	2.00	5.00	7.00
F / N	20.0	60.0	60.0	20.0

(a) Determine the net work done on the trolley between $s = 0$ and $s = 7.00$ m. [2]

(b) Hence calculate the speed of the trolley at $s = 7.00$ m. [2]

(c) Determine the instantaneous power transferred to the trolley by the resultant force at $s = 7.00$ m. [2]

Question 4

A trolley is released from rest at point A on a track. The track is smooth from A to B and rough from B to C. Heights are measured above the same horizontal reference level. Air resistance is negligible.

Data:

Trolley mass: 0.650 kg

Height of A: 3.40 m

Height of B: 1.20 m

Height of C: 0.400 m

Speed at C: 6.00 m s^{-1}

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Take $g = 9.81\ \text{m s}^{-2}$.

(a) Show that the speed of the trolley at B is about $6.6\ \text{m s}^{-1}$. [2]

(b) Determine the work done against friction between B and C. [3]

(c) Explain how energy is conserved between B and C when the trolley, track and Earth are treated as a closed system. [2]

Question 5

An electric motor raises a loaded platform vertically at constant speed. A constant resistive force acts downwards. The useful output is defined as the increase in gravitational potential energy of the platform and load.

Data:

Combined mass of platform and load: 48.0 kg

Upward speed: $0.320\ \text{m s}^{-1}$

Resistive force: 25.0 N

Electrical input power: 0.240 kW

Take $g = 9.81\ \text{m s}^{-2}$.

(a) Determine the upward force exerted by the motor on the platform. [2]

(b) Calculate the mechanical power delivered by the motor to the platform, in W. [2]

(c) Determine the efficiency of the lifting system. [2]

(d) A Sankey diagram represents the energy transfers during 20.0 s of lifting at this speed. It has one electrical input branch, one useful output branch and one branch for all wasted energy. Determine the energy labels, in kJ, for the input branch and the wasted-energy branch. [2]

Question 6

A testing sledge is launched along a horizontal guide by a compressed spring. The sledge starts from rest and remains in contact with the spring until the spring reaches its natural length. It then separates from the spring, travels a further 1.50 m horizontally and climbs a straight ramp to point T.

A constant resistive force opposes the motion over the entire path, including during contact with the spring. Air resistance is negligible. The spring has negligible mass. Its force has magnitude $F = kx$, where x is its compression.

Data:

Sledge mass: 1.20 kg

Spring constant: $640\ \text{N m}^{-1}$

Initial spring compression: 0.250 m

Resistive force: 2.00 N

Ramp length to T: 1.60 m

Vertical height of T above the horizontal guide: 0.800 m

Take $g = 9.81\ \text{m s}^{-2}$.

(a) Show that the speed of the sledge when it separates from the spring is about $5.7\ \text{m s}^{-1}$. [2]

(b) Determine the speed of the sledge when the spring compression has decreased to 0.125 m. [2]

(c) Hence calculate the instantaneous power delivered by the spring to the sledge at a compression of 0.125 m. [2]

(d) Determine the acceleration of the sledge at a spring compression of 0.125 m. [2]

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(e) Calculate the speed of the sledge at T. [2]

(f) The initial spring compression is now adjusted. The spring's natural-length position, the horizontal distance after separation and the ramp remain fixed. Determine the minimum initial compression required for the sledge to reach T. [2]

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Markscheme

Question 1

(a)

$W = 36.0 \times 4.50 \cos 35.0°$ **1**

$W = 133\ \text{J}$ **1**

Accept equivalent forms.

(b)

The normal reaction does zero work. **1**

The normal reaction is perpendicular to the displacement.

Question 2

(a)

$E_k = \dfrac{12.0^2}{2(0.800)}$ **1**

$E_k = 90.0\ \text{J}$ **1**

(b)

$\dfrac{1}{2}(0.800)v^2 = 90.0 + 70.0$ **1**

$v = 20.0\ \text{m s}^{-1}$ **1**

ECF from part (a).

Question 3

(a)

$W = \dfrac{20.0 + 60.0}{2}(2.00) + 60.0(3.00) + \dfrac{60.0 + 20.0}{2}(2.00)$ **1**

$W = 340\ \text{J}$ **1**

Accept any equivalent decomposition of the area under the graph.

(b)

$\dfrac{1}{2}(2.40)v^2 = 340$ **1**

$v = 16.8\ \text{m s}^{-1}$ **1**

ECF from part (a).

(c)

$P = 20.0v$, using the speed at $s = 7.00$ m. **1**

$P = 337\ \text{W}$ **1**

ECF from part (b). Accept 336 W *when the rounded speed* $16.8\ \text{m s}^{-1}$ *is used.*

Question 4

(a)

$\dfrac{1}{2}mv_B^2 + mg(1.20) = mg(3.40)$ **1**

$v_B = \sqrt{2(9.81)(3.40 - 1.20)} = 6.57\ \text{m s}^{-1} \approx 6.6\ \text{m s}^{-1}$ **1**

A numerical substitution leading to the stated result is required.

(b)

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$E_B = \frac{1}{2}mv_B^2 + mg(1.20) = 21.6801$ J **1**

$E_C = \frac{1}{2}(0.650)(6.00)^2 + (0.650)(9.81)(0.400) = 14.2506$ J **1**

$W_{\text{against friction}} = E_B - E_C = 7.43$ J **1**

Accept determining E_B directly from the gravitational potential energy at A. ECF from part (a); using 6.60 m s^{-1} gives 7.56 J. The work done by friction is negative, but the requested work done against friction is positive.

(c)

Mechanical energy is transformed into thermal energy in the trolley and track. OWTTE **1**

The thermal energy increase equals the mechanical energy decrease, so the total energy of the closed system is unchanged. OWTTE **1**

Question 5

(a)

$F = mg + 25.0 = 48.0(9.81) + 25.0$ **1**

$F = 496$ N **1**

The resultant force is zero because the speed is constant.

(b)

$P = F(0.320)$ **1**

$P = 159$ W **1**

ECF from part (a).

(c)

$\eta = \frac{mgv}{P_{\text{input}}} = \frac{48.0(9.81)(0.320)}{240}$ **1**

$\eta = 0.628$ or 62.8%. **1**

Accept useful power calculated as the answer to part (b) minus 25.0(0.320) W, with ECF from part (b).

(d)

$E_{\text{input}} = 0.240(20.0) = 4.80$ kJ **1**

$E_{\text{wasted}} = 4.80 - \frac{48.0(9.81)(0.320)(20.0)}{1000} = 1.79$ kJ **1**

ECF from part (c) for wasted energy calculated using $E_{\text{input}}(1-\eta)$. Wasted energy includes dissipation within the motor and work against the resistive force.

Question 6

(a)

$\frac{1}{2}(640)(0.250)^2 = \frac{1}{2}(1.20)v^2 + 2.00(0.250)$ **1**

$v = \sqrt{\frac{2(19.5)}{1.20}} = 5.70 \text{ m s}^{-1} \approx 5.7 \text{ m s}^{-1}$ **1**

A numerical substitution leading to the stated result is required.

(b)

$\frac{1}{2}(1.20)v^2 = \frac{1}{2}(640)(0.250^2 - 0.125^2) - 2.00(0.125)$ **1**

$v = 4.96 \text{ m s}^{-1}$ **1**

The distance travelled is the decrease in compression.

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(c)

$P = Fv = (640)(0.125)v$ **1**

$P = 397$ W **1**

ECF from part (b). This is the power delivered by the spring.

(d)

$(1.20)a = 640(0.125) - 2.00$ **1**

$a = 65.0\ \text{m s}^{-2}$, in the direction of motion. **1**

This part links energy and power to Newton's second law.

(e)

$\frac{1}{2}(1.20)v_T^2 = \frac{1}{2}(640)(0.250)^2 - 2.00(0.250 + 1.50 + 1.60) - 1.20(9.81)(0.800)$ **1**

$v_T = 2.54\ \text{m s}^{-1}$ **1**

Accept an energy equation starting at the separation point, with ECF from part (a). Using $5.70\ \text{m s}^{-1}$ gives $2.54\ \text{m s}^{-1}$.

(f)

$\frac{1}{2}(640)x^2 = 1.20(9.81)(0.800) + 2.00(x + 1.50 + 1.60)$, with zero kinetic energy at T. **1**

Solving $320x^2 - 2.00x - 15.6176 = 0$ gives the positive root $x = 0.224$ m. **1**

Accept a numerical solution. The resistive work during spring contact changes when the initial compression changes.

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