MEGA LECTURE

# IB DP PHYSICS

## Theme A · Space, Time and Motion

## MARK SCHEME

A.1 Kinematics · A.2 Forces and Momentum · A.3 Work, Energy and Power
A.4 Rigid Body Mechanics (HL) · A.5 Relativity (HL)

Standard and Higher Level · Syllabus 2025

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Original exam-style questions written for the IB Diploma Programme Physics course (first assessment 2025)

## Section A — Multiple Choice: Answer Key (15 marks)

**1.** Answer: **B** — $v = u - gt = 15 - (9.8 \cdot 2) = -4.6$ m $s^{-1}$ (i.e. 4.6 m $s^{-1}$ downward).

**2.** Answer: **B** — Instantaneous velocity is the gradient of the tangent to an s−t graph; area under a v−t graph would instead give displacement.

**3.** Answer: **C** — $v^2 = u^2 + 2as \Rightarrow a = (22^2 - 4.0^2)/(2 \cdot 130) = 468/260 = 1.8$ m $s^{-2}$.

**4.** Answer: **B** — $a = F/m = 15/5.0 = 3.0$ m $s^{-2}$ (Newton's second law).

**5.** Answer: **B** — Third-law pairs act on different objects, are the same type of interaction, and are equal in magnitude but opposite in direction.

**6.** Answer: **B** — Momentum conservation: $(2.0 \cdot 3.0) = (2.0+4.0)v \Rightarrow v = 6.0/6.0 = 1.0$ m $s^{-1}$.

**7.** Answer: **C** — $P = Fv = mgv = 500 \cdot 9.8 \cdot 2.0 = 9800$ W = 9.8 kW.

**8.** Answer: **B** — Momentum, total energy, and mass are always conserved in an isolated system; kinetic energy is conserved only in elastic collisions.

**9.** Answer: **B** — $E_p = ½kx^2 = 0.5 \cdot 200 \cdot 0.15^2 = 2.25$ J.

**10.** Answer: **B** — $\tau = Fr = 20 \cdot 0.30 = 6.0$ N m.

**11.** Answer: **C** — I = ■⁄■$mr^2 = 0.4 \cdot 3.0 \cdot 0.20^2 = 0.048$ kg $m^2$.

**12.** Answer: **A** — This is the rotational analogue of conservation of linear momentum: L is conserved when net external torque = 0.

**13.** Answer: **C** — $\gamma = 1/\sqrt{(1 - 0.60^2)} = 1/\sqrt{(0.64)} = 1/0.80 = 1.25$.

**14.** Answer: **B** — Time dilation: a moving clock is observed to run slow compared to a clock at rest in the observer's frame.

**15.** Answer: **B** — Proper length $L_0$ is measured in the frame in which the object is at rest; any other observer measures a shorter, contracted length.

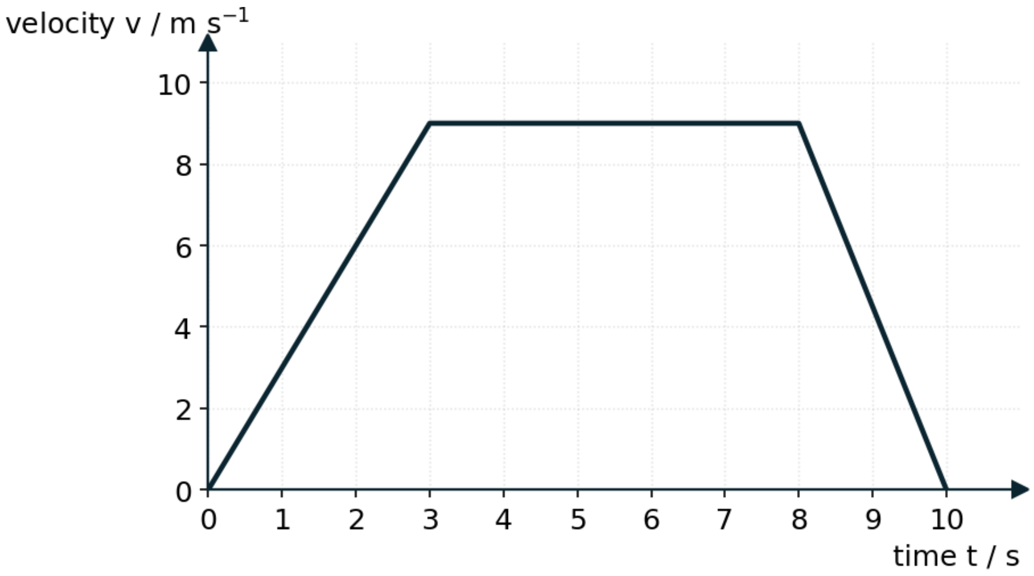
# Section B — Structured Questions: Worked Solutions (70 marks)

Mark-scheme notation: M = method mark, A = accuracy mark (dependent on the preceding M mark), R = reasoning mark.

## A.1 Kinematics

**Question 1** [7 marks]

A sprinter accelerates uniformly from rest to a maximum speed, holds that speed, then decelerates uniformly to rest. The graph below shows her velocity during the run.




*Velocity–time graph for the sprint (values on the axes are the given data for this question).*

**(a)** Calculate the sprinter's acceleration during the first 3.0 s. **[2]**

$a = \Delta v/\Delta t = 9.0/3.0 =$ **3.0 m s$^{-2}$**. **M1 A1**

**(b)** Show that the total distance covered during the 10 s run is about 68 m. **[3]**

Distance = area under the graph = ½(3.0)(9.0) + (9.0)(5.0) + ½(2.0)(9.0) = 13.5 + 45 + 9.0 = **67.5 m** ≈ 68 m. **M1 M1 A1**

**(c)** Calculate her average velocity for the whole 10 s run. **[2]**

$v_{avg}$ = total distance / total time = 67.5/10 = **6.75 m s$^{-1}$**. **M1 A1**

**Question 2** [7 marks]

A stone is kicked horizontally at 12 m s$^{-1}$ from the top of a cliff of height 20 m. Air resistance is negligible; take g = 9.8 m s$^{-2}$.

**(a)** Calculate the time taken for the stone to reach the ground. **[2]**

$h = \frac{1}{2}gt^2 \Rightarrow t = \sqrt{2h/g} = \sqrt{2 \cdot 20/9.8} =$ **2.02 s**. **M1 A1**

**(b)** Calculate the horizontal distance travelled before landing. **[2]**

$x = u_x t = 12 \cdot 2.02 =$ **24.2 m**. **M1 A1**

**(c)** Calculate the stone's speed as it hits the ground. **[3]**

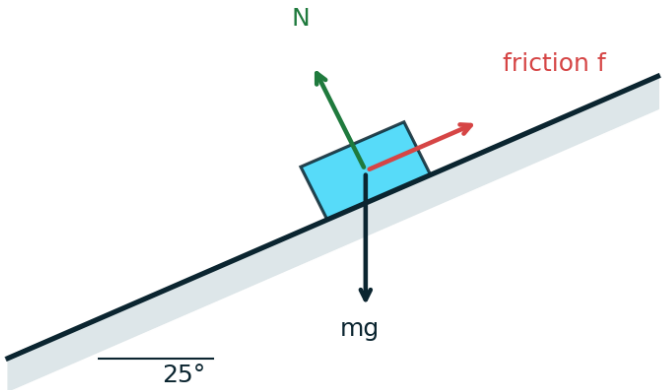
$v_y = gt = 9.8 \cdot 2.02 = 19.8$ m s$^{-1}$ **M1 M1 A1**
$v = \sqrt{(v_x^2 + v_y^2)} = \sqrt{(12^2 + 19.8^2)} =$ **23.2 m s$^{-1}$**.

## A.2 Forces and Momentum

**Question 3** [7 marks]

A 12 kg box rests on a rough incline at 25° to the horizontal, as shown. The coefficient of static friction between the box and the incline is 0.40. Take $g = 9.8$ m s$^{-2}$.

12 kg box on a rough incline (μ = 0.40)




*Forces on the box: weight mg, normal force N, and friction f acting up the slope.*

**(a)** Calculate the component of the box's weight acting along the incline (down the slope). **[2]**

$mg \sin\theta = 12 \cdot 9.8 \cdot \sin 25° =$ **49.7 N**. **M1 A1**

**(b)** Calculate the normal force acting on the box. **[2]**

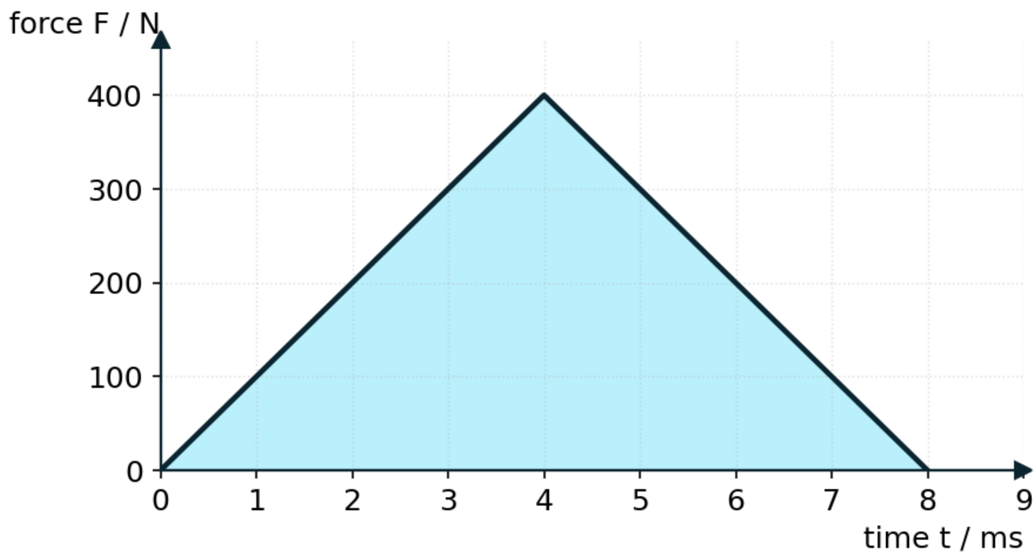
$N = mg \cos\theta = 12 \cdot 9.8 \cdot \cos 25° =$ **106.6 N**. **M1 A1**

**(c)** Determine, showing your reasoning, whether the box remains stationary or begins to slide. **[3]**

Maximum available friction = $\mu N = 0.40 \cdot 106.6 = 42.6$ N. **M1 A1 R1**
Since the down-slope component (49.7 N) is **greater than** the maximum friction (42.6 N), the box **slides**.

**Question 4** [6 marks]

A 0.50 kg ball is struck by a bat. The graph shows how the force on the ball varies during the 8.0 ms contact time.




*Force–time graph for the bat–ball impact (given data).*

**(a)** Calculate the impulse delivered to the ball during the impact. **[2]**

Impulse = area under graph = ½(400)(8.0×$10^{-3}$) = **1.60 N s**. **M1 A1**

**(b)** Calculate the change in the ball's velocity, assuming it was at rest just before impact. **[2]**

Δv = J/m = 1.60/0.50 = **3.2 m $s^{-1}$**. **M1 A1**

**(c)** Calculate the average force exerted on the ball during the impact. **[2]**

$F_{avg}$ = J/Δt = 1.60/(8.0×$10^{-3}$) = **200 N**. **M1 A1**

## A.3 Work, Energy and Power

**Question 5** [8 marks]

A skier of mass 65 kg starts from rest at the top of a slope of vertical height 40 m. Take g = 9.8 m $s^{-2}$.

**(a)** Calculate the loss in gravitational potential energy as the skier descends to the bottom. **[2]**

$E_p$ = mgh = 65·9.8·40 = **25480 J** (≈ 2.5×$10^4$ J). **M1 A1**

**(b)** Assuming no energy is lost to friction or air resistance, calculate the skier's speed at the bottom of the slope. **[3]**

Energy conservation: ½$mv^2$ = mgh ⇒ v = √(2gh) = √(2·9.8·40) = **28.0 m $s^{-1}$**. **M1 M1 A1**

**(c)** In reality the skier's speed at the bottom is measured to be 24 m $s^{-1}$. Calculate the energy transferred to thermal energy by friction and air resistance. **[3]**

$KE_{actual}$ = ½$mv^2$ = 0.5·65·$24^2$ = 18720 J. **M1 A1 A1**
Energy lost = $E_p$ − $KE_{actual}$ = 25480 − 18720 = **6760 J** (≈ 6.8×$10^3$ J).

**Question 6** [6 marks]

An electric motor lifts a 15 kg load a vertical height of 6.0 m in 8.0 s, moving at constant speed. The electrical energy supplied to the motor during this time is 1500 J. Take g = 9.8 m $s^{-2}$.

**(a)** Calculate the useful work done in lifting the load. **[2]**

W = mgh = 15·9.8·6.0 = **882 J**. **M1 A1**

**(b)** Calculate the efficiency of the motor. **[2]**

efficiency = (useful output / total input)×100% = (882/1500)×100 = **58.8%**. **M1 A1**

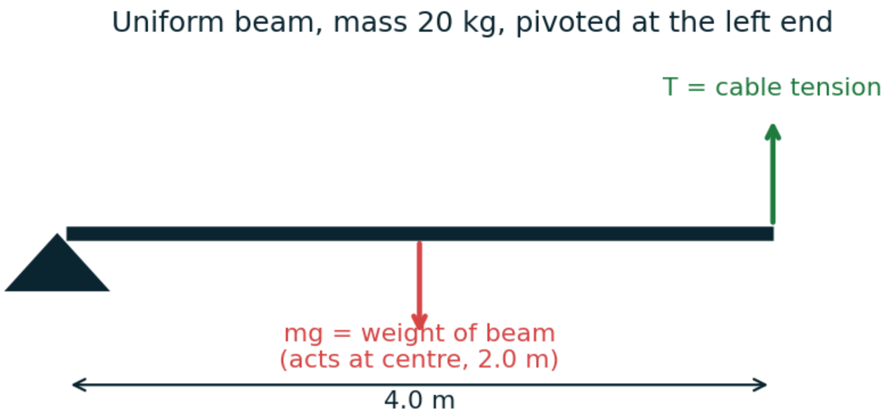
**(c)** Calculate the useful power output of the motor. **[2]**

P = W/t = 882/8.0 = **110 W**. **M1 A1**

## A.4 Rigid Body Mechanics (HL)

**Question 7** [8 marks]

A uniform beam of length 4.0 m and mass 20 kg is pivoted (hinged) at one end and held horizontal by a vertical cable attached at its far end, as shown. Take g = 9.8 m $s^{-2}$.




*Uniform beam in rotational equilibrium about the pivot.*

**(a)** Calculate the torque produced about the pivot by the beam's own weight. **[2]**

Weight acts at the centre of mass, 2.0 m from the pivot: τ = mg·2.0 = 20·9.8·2.0 = **392 N m**. **M1 A1**

**(b)** Hence calculate the tension T in the cable, which acts vertically at the far end of the beam, 4.0 m from the pivot. **[3]**

For rotational equilibrium: T·4.0 = 392 ⇒ T = 392/4.0 = **98 N**. **M1 M1 A1**

**(c)** An additional 10 kg mass is now hung from the far end of the beam. Calculate the new tension in the cable. **[3]**

Extra torque = (10·9.8)·4.0 = 392 N m. **M1 M1 A1**
Total torque = 392 + 392 = 784 N m.
$T_{new}$ = 784/4.0 = **196 N**.

**Question 8** [8 marks]

A solid cylinder of mass 2.0 kg and radius 0.10 m (I = ½$mr^2$ for a solid cylinder about its central axis) rolls without slipping from rest down a slope, reaching the bottom with a linear speed of 4.0 m $s^{-1}$. Take g = 9.8 m $s^{-2}$.

**(a)** Calculate the cylinder's angular velocity at the bottom of the slope. **[2]**

$\omega = v/r = 4.0/0.10 =$ **$40$ rad $s^{-1}$**. **M1 A1**

**(b)** Show that the cylinder's total kinetic energy at the bottom is about 24 J. **[3]**

$I = \frac{1}{2}mr^2 = 0.5 \cdot 2.0 \cdot 0.10^2 = 0.010$ kg $m^2$. **M1 M1 A1**
$KE_{trans} = \frac{1}{2}mv^2 = 16$ J; $KE_{rot} = \frac{1}{2}I\omega^2 = 8$ J.
$KE_{total} = 16 + 8 =$ **24 J**.

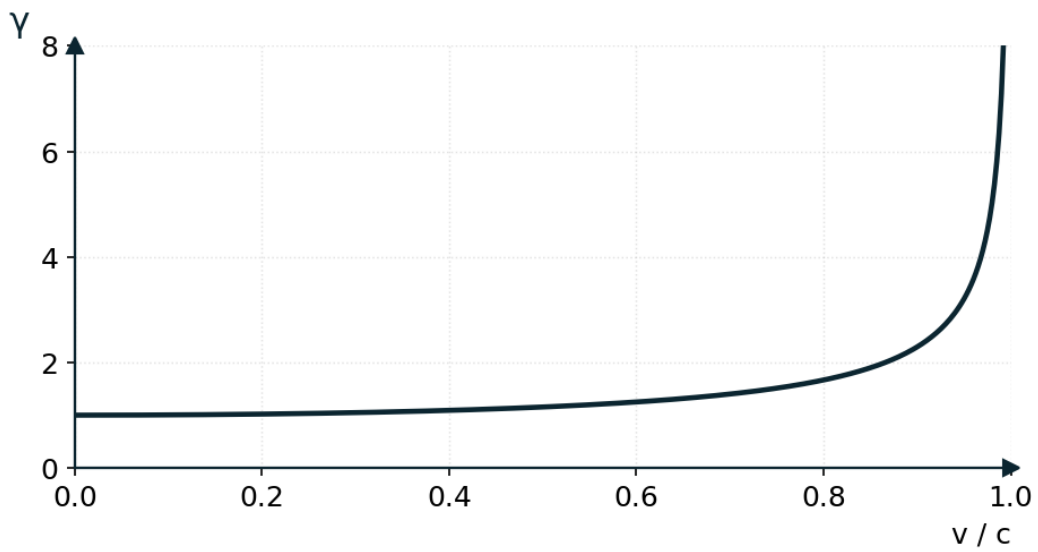
**(c)** Assuming no energy is lost to friction, calculate the vertical height of the slope. **[3]**

Energy conservation: $mgh = KE_{total} \Rightarrow h = 24/(2.0 \cdot 9.8) =$ **1.22 m**. **M1 M1 A1**

## A.5 Relativity (HL)

**Question 9** [7 marks]

A muon is created in the upper atmosphere and travels toward the Earth's surface at v = 0.98c. In the muon's own rest frame, its (proper) lifetime is 2.2 μs. The graph below shows how the Lorentz factor γ varies with speed v/c.




*γ as a function of v/c (reference curve — read off approximately, then verify by calculation in part (a)).*

**(a)** Calculate the Lorentz factor γ for the muon. **[2]**

$\gamma = 1/\sqrt{(1 - (v/c)^2)} = 1/\sqrt{(1 - 0.98^2)} =$ **5.03**. **M1 A1**

**(b)** Calculate the muon's lifetime as measured by an observer on the ground. **[2]**

$\Delta t = \gamma \Delta t_0 = 5.03 \cdot 2.2 =$ **11.1** **μs**. **M1 A1**

**(c)** Using this dilated lifetime, calculate the distance (in the Earth's frame) that the muon travels before it decays. **[3]**

$d = v\Delta t = 0.98 \cdot (3.0 \times 10^8) \cdot (11.1 \times 10^{-6}) =$ **3250 m** (≈ 3.25 km). **M1 M1 A1**

**Question 10** [6 marks]

A spacecraft has a proper length of 120 m. It travels past the Earth at v = 0.80c.

**(a)** Calculate the Lorentz factor γ for the spacecraft's motion. **[2]**

$\gamma = 1/\sqrt{(1 - 0.80^2)}$ = **1.667**. **M1 A1**

**(b)** Calculate the spacecraft's length as measured by an observer on Earth. **[2]**

$L = L_0/\gamma$ = 120/1.667 = **72.0 m**. **M1 A1**

**(c)** The crew measure a journey time of 100 s using the spacecraft's own clock. Calculate the time for the same journey as measured by an observer on Earth. **[2]**

$\Delta t_{Earth} = \gamma \Delta t_0$ = 1.667·100 = **166.7 s**. **M1 A1**