

Exercise walk-through

# 11.2

## Simple harmonic motion (full C.1, HL)

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International Baccalaureate · IB Diploma · Physics · HL

# Oscillations · 2.1

## Reasoning

Simple harmonic motion has acceleration proportional to displacement and directed toward equilibrium. Period is time per cycle; frequency is its reciprocal. Damping transfers energy away from the oscillating system. resonance : A large response to periodic forcing near a natural frequency; damping: Energy transfer out of an oscillating system.

# Oscillations · 3.1

## Reasoning

Velocity is greatest near equilibrium for ideal SHM, while acceleration magnitude is greatest at extreme displacement. Resonance can occur near the natural frequency under periodic driving, with amplitude limited by damping. Measure time for several complete oscillations and divide. Define a cycle consistently and use a small displacement when the model requires it. Keep pendulum paths clear and record damping effects rather than assuming perfect motion.

## Energy halfway to an extreme

- 1 Set the model**  $m = 0.20 \text{ kg}$ , amplitude  $x_0 = 0.040 \text{ m}$ ,  $\omega = 5.0 \text{ rad/s}$ . Find the speed at  $x = 0.020 \text{ m}$ .
- 2 Calculate**  $E_T = 0.0040 \text{ J}$ ;  $E_p = 0.0010 \text{ J}$ ;  $E_k = 0.0030 \text{ J}$ . Hence  $|v| = \sqrt{2E_k/m} = 0.173 \text{ m/s}$ .

### Decision

Energy gives speed magnitude. The phase or direction of motion determines the sign of velocity.

## Exercises 2.1·2.3

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**2.1** State the defining equation of simple harmonic motion and explain the significance of its minus sign. [2]

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**2.2** A mass–spring system has  $m = 0.30$  kg and  $k = 12$  N/m. Calculate its period and angular frequency. [3]

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**2.3** An oscillator with amplitude  $x_0$  passes through equilibrium at  $t = 0$ . State its phase constant  $\phi$ , and give its displacement and speed at  $t = 0$  in terms of  $x_0$  and  $\omega$ . [3]

## Exercises 2.1·2.3

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**2.1** State the defining equation of simple harmonic motion and explain the significance of its minus sign. [2]

**2.1**  $a = -\omega^2 x$ ; acceleration always opposes displacement – directed toward equilibrium, the restoring condition.

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**2.2** A mass–spring system has  $m = 0.30$  kg and  $k = 12$  N/m. Calculate its period and angular frequency. [3]

**2.2**  $T = 2\pi\sqrt{0.30/12} = 2\pi(0.158) = 0.99$  s;  $\omega = 2\pi/T = 6.3$  rad/s.

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**2.3** An oscillator with amplitude  $x_0$  passes through equilibrium at  $t = 0$ . State its phase constant  $\phi$ , and give its displacement and speed at  $t = 0$  in terms of  $x_0$  and  $\omega$ . [3]

**2.3**  $\phi = 0$ ;  $x = 0$  at equilibrium;  $v = \omega x_0$ , its maximum.

## Exercises 2.4·3.2

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**2.4** For the same oscillator, write the total energy and the potential energy at displacement  $x$ , and state where in the cycle each of kinetic, potential and total energy is greatest. [3]

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**3.1** A 0.25 kg mass on a spring oscillates with amplitude 0.060 m and angular frequency 8.0 rad/s. Calculate the total energy, the maximum speed, and the speed at  $x = 0.030$  m. [5]

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**3.2** A simple pendulum of length 0.90 m ( $g = 9.8 \text{ m/s}^2$ ) is released from rest at a  $5.0^\circ$  angle, giving amplitude  $x_0 = 0.079$  m. Calculate the period, and the maximum speed of the bob. [4]

## Exercises 2.4·3.2

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**2.4** For the same oscillator, write the total energy and the potential energy at displacement  $x$ , and state where in the cycle each of kinetic, potential and total energy is greatest. [3]

**2.4**  $E_T = \frac{1}{2}m\omega^2x_0^2$ ;  $E_p = \frac{1}{2}m\omega^2x^2$ ; kinetic greatest at equilibrium, potential greatest at the extremes ( $x = \pm x_0$ ), total the same everywhere.

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**3.1** A 0.25 kg mass on a spring oscillates with amplitude 0.060 m and angular frequency 8.0 rad/s. Calculate the total energy, the maximum speed, and the speed at  $x = 0.030$  m. [5]

**3.1**  $E_T = \frac{1}{2}(0.25)(64)(0.0036) = 2.9 \times 10^{-2}$  J;  $v_{max} = \omega x_0 = 8.0 \times 0.060 = 0.48$  m/s;  
 $v = \omega\sqrt{x_0^2 - x^2} = 8.0\sqrt{0.0036 - 0.00090} = 8.0(0.0520) = 0.42$  m/s.

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**3.2** A simple pendulum of length 0.90 m ( $g = 9.8$  m/s<sup>2</sup>) is released from rest at a 5.0° angle, giving amplitude  $x_0 = 0.079$  m. Calculate the period, and the maximum speed of the bob. [4]

**3.2**  $T = 2\pi\sqrt{0.90/9.8} = 2\pi(0.303) = 1.9$  s;  $v_{max} = \omega x_0$  with  $\omega = 2\pi/1.9 = 3.3$  rad/s;  
 $v_{max} = 3.3 \times 0.079 = 0.26$  m/s.

## Exercise 3.3

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**3.3** A particle in SHM is described by  $x = 0.050 \sin(4\pi t)$  m. State the amplitude, period and phase constant, and calculate the earliest time at which the speed is maximum. [4]

## Exercise 3.3

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**3.3** Amplitude 0.050 m;  $\omega = 4\pi$ , so  $T = 2\pi/\omega = 0.50$  s;  $\phi = 0$ . Speed  $v = \omega x_0 \cos(4\pi t)$  is maximum when  $\cos(4\pi t) = \pm 1$ , first at  $t = 0$  – the particle starts at equilibrium moving positive.