SKJ Education

LC HL PHYSICS

CORE PHYSICS PROGRAM: WEEK 1

CIRCULAR MOTION

Steven James
steven@skjeducation.com
www.skjeducation.com

LC HL PHYSICS – CORE PHYSICS PROGRAM

Week 1: Circular Motion

Learning Objectives

- To explain and apply the principles of circular motion, including the concept of the radian, angular velocity, and tangential velocity.
- To calculate centripetal acceleration and force and solve problems involving circular motion.

Key Terms - Week 1

- **Circular Motion:** Motion in a circular path, characterized by a constant radius and a changing direction.
- **Radian:** A unit of angular measurement, defined as the angle subtended at the center of a circle by an arc equal in length to the radius.
- **Angular Velocity (ω):** The rate of change of angular displacement, measured in radians per second (rad/s).
- **Tangential Velocity (v):** The velocity of an object moving in a circular path, tangent to the circle, given by $v = r\omega$.
- **Centripetal Acceleration (a_c):** The acceleration directed towards the center of a circular path, given by $a_c = \frac{v^2}{r} = r\omega^2$.
- **Centripetal Force (F_c):** The force required to maintain an object in circular motion, directed towards the center of the circle, given by $F_c = \frac{mv^2}{r} = mr\omega^2$.
- **Applications of Circular Motion:** Examples include planetary orbits, circular motion in amusement park rides, and the motion of charged particles in magnetic fields.

Weekly *Challenge*: Investigate a real-world example of circular motion, such as a car navigating a roundabout or a satellite in orbit. Analyse the forces involved and calculate the centripetal acceleration and force. Share your findings on Google Classroom.

WEEK 1 STUDY PLAN

Day	Activities & Time Commitment	✓	Rating (1-10)
Monday	- Review Learning Objectives (5 min) - Rank your current ability (5 min) - Review Key Terms (10 min) - Complete Exercise A1 (15 min) - Watch Video (Exercise A2) (20 min) *Focus: PREPARATION*		
Tuesday	- Complete Exercise B (60 min) *Focus: QUESTIONING*		
Wednesday	- Reflect on content so far (what has been challenging?) (10 min) - Plan remaining study sessions (10 min) *Focus: PROCESSING*		
Thursday	- Complete Exercise C (30 min) - 1-hour online lesson (60 min) *Focus: ERROR ANALYSIS*		
Friday	- Complete Exercise D (45 min) *Focus: REVISION*		
Saturday	- Complete Exam Question Assessment (D) (60 min) *Focus: EXECUTION*		
Sunday	- Correct assessment (30 min) - Complete self-reflection (15 min) - Plan next week (15 min) *Focus: REFLECTION & RECHARGING*		

Study Tips for Success

- **Active Recall:** After studying, close your notes and write down **everything you remember**. Force your brain to grow.
- **Spaced Repetition:** Review concepts **multiple times** over several days.
- **Physics in Action:** Look for **real-world examples** of the concepts you're learning.
- **Ask Questions:** Don't hesitate to ask for help when concepts are unclear. Reach out via *Google Classroom* or email; *steven@skjeducation.com*.
- **Celebrate Progress:** **Acknowledge your improvements**, no matter how small.

A1. Proficiency Drills

Learning Focus: Mastering the fundamentals of **circular motion**, including **radians**, **angular velocity**, and **centripetal acceleration**.

Part 1: Angular Measurement - Radians vs. Degrees

Key Concepts

The Radian: A unit of angular measurement. One radian is the angle subtended at the centre of a circle by an arc equal in length to the radius.
Conversion: 360ř $= 2\pi$ radians. Thus, 1 radian $= \frac{180}{\pi}$ degrees $\approx$ 57.3ř.
Angular Displacement (θ): Measured in radians.
Angular Velocity (ω): The rate of change of angular displacement. Measured in radians per second (rad/s).
$\omega = \frac{\Delta\theta}{\Delta t}$.

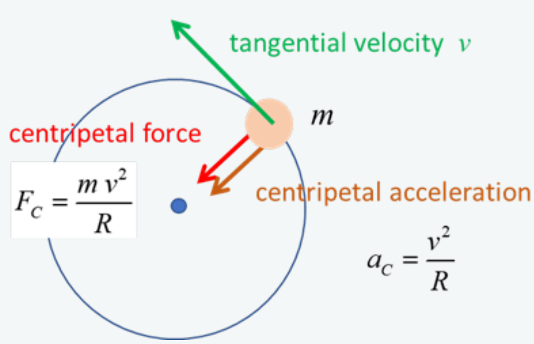
Task #1: Convert between radians and degrees.

1. $90° =$ ______________________ radians
2. $\frac{\pi}{4}$ radians $=$ ______________________ °
3. $180° =$ ______________________ radians
4. 2 radians $=$ ______________________ ° (approx.)

Part 2: Circular Motion - The Maths

Essential Formulae

Tangential/Linear Velocity (v): The instantaneous velocity of an object moving in a circle. It is **tangent** to the circle.
$v = r\omega$ (where r is the radius).
Centripetal Acceleration ($\mathbf{a}_c$): The acceleration directed towards the centre of the circle.
$a_c = \frac{v^2}{r} = r\omega^2$.
Centripetal Force ($\mathbf{F}_c$): The net force directed towards the centre of the circle, causing the centripetal acceleration.
$F_c = \frac{mv^2}{r} = mr\omega^2$.



Task #2: Perform these basic calculations.

1. A wheel rotates at 120 revolutions per minute (RPM). What is its angular velocity (ω) in rad/s?
2. A car travels around a circular track of radius 50 m at a constant speed of 20 m/s. What is its centripetal acceleration?
3. An object moves in a circle of radius 2.0 m with an angular velocity of 3.0 rad/s. What is its tangential velocity?
4. A 1500 kg car goes around a curve of radius 40 m at a speed of 25 m/s. What is the magnitude of the centripetal force acting on it?

Part 3: Applying Circular Motion

Physics Vocabulary

- **Centrifugal Force:** A **fictitious force** that appears to act outward on an object in circular motion when viewed from a rotating frame of reference. It is not a real force in an inertial frame.
- **Uniform Circular Motion:** Motion in a circle at a **constant speed**. The velocity is **not constant** due to the changing direction.

Task #3: A satellite orbits the Earth at a height where its orbital period is 90 minutes.

Satellite Analysis

Question	**Your Answer**
a) What is its angular velocity (ω) in rad/s?	____ rad/s
b) If the radius of its orbit is 7000 km, what is its tangential velocity?	____ m/s

Answers:

- **Task #1:** 1. $\frac{\pi}{2}$ rad, 2. 45°, 3. π rad, 4. 114.6°.
- **Task #2:**
  1. 4π rad/s (or 12.57 rad/s)
  2. 8 m/s^2
  3. 6 m/s
  4. 23,438 N
- **Task #3:** a) 1.16×10^{-3} rad/s, b) 8.14 km/s (or 8140 m/s)

Task #4: Challenge Questions

Attempt as many questions as quickly as possible. Pay close attention to units and whether the motion is uniform or not.

1. A cyclist is riding around a circular track with a radius of 25 m at a constant speed of 10 m/s. Calculate the cyclist's centripetal acceleration and the magnitude of the centripetal force acting on the cyclist (mass = 70 kg).
2. A car is travelling around a bend in the road. The bend can be considered a part of a circle with a radius of 50 m. If the car has a mass of 1200 kg and is travelling at a speed of 15 m/s, what is the frictional force acting on the car?
3. A stone is tied to a string and whirled in a vertical circle at a constant speed. Explain why the tension in the string is not the same at the top and bottom of the circle.
4. A satellite is in a geostationary orbit around the Earth. What does this imply about its orbital period and how does it relate to the Earth's rotation?

A2. Video Suggestion

Watch: Centripetal force — Physics — Khan Academy
Link: `https://www.youtube.com/watch?v=4bMawIIWi7w`
Why: This video provides a clear, visual explanation of centripetal force—the inward force that keeps an object moving in a circle. It breaks down the concept using everyday examples and simple diagrams, making it easier to understand how circular motion works, why you feel pushed outward on a merry-go-round (even though the force is actually inward), and how to apply the formulae. Khan Academy's approach is step-by-step, so you can pause, rewatch, and really grasp the physics behind rotation before moving on to problem-solving.

B. The 60-Minute Deep Think

Think First, Calculate Second This exercise is built on a **Predict** → **Explain** → **Solve** → **Reflect** cycle. The marks are in the reasoning. Spend at least 15 minutes on Parts 1 & 2 before doing any major calculation. Draw all the diagrams yourself, labeling all key features.

Part 1: 15 mins - Conceptual Understanding

Scenario: The Spinning Astronaut's Paradox

An astronaut is training in a centrifuge—a long arm that rotates horizontally about a central axis. She sits in a capsule at the end of the arm, 8 meters from the center. As the centrifuge spins at constant angular velocity, she holds a small ball and releases it from rest *relative to herself.*

Diagram: A top-down view showing a horizontal arm rotating counterclockwise about a central pivot. The astronaut's capsule is at the outer end. An arrow indicates the direction of rotation. The ball is shown at the moment of release, in the astronaut's hand.

1. **Predict:** From the astronaut's perspective inside the spinning capsule, which way does the ball appear to move immediately after release—radially outward (away from the center), radially inward (toward the center), or in some other direction? What about from the perspective of a stationary observer standing on the ground watching the centrifuge?
2. **Explain Your Reasoning:** Why do you think the ball moves that way in each reference frame? What force (or absence of force) is responsible? Articulate your initial mental model without using any equations.
3. **Connect:** What fundamental principle about circular motion and forces is the key to unraveling this apparent paradox between what the astronaut experiences and what actually happens?

Instructions to Student: "Write your full answers to these questions before moving on. Resist the urge to look ahead—your initial reasoning, even if flawed, is valuable data for your learning."

Part 2: 20 mins - Strategic Deconstruction

Deconstruction

Step A: Diagrammatic Reasoning

Sketch three clear, labeled diagrams for this scenario:

1. A **top-down path diagram** showing: (a) the circular path of the astronaut before and after release, and (b) the path of the ball after release, as seen by the stationary ground observer. Mark the point of release clearly and indicate the instantaneous velocity direction of the ball at release.
2. A **free-body diagram** of the ball at three moments: (a) just before release (while held), (b) at the instant of release, and (c) shortly after release. Label all forces acting on the ball at each moment. *Hint: Consider what provides the centripetal force before release.*
3. A **velocity vector diagram** at the point of release showing: the tangential velocity v_t, the position vector r from the center, and the direction of centripetal acceleration a_c that *was* acting on the ball before release.

Step B: Qualitative Principle

State the fundamental physics principle that governs what happens to the ball after release. Your answer should address:

- Newton's First Law and what happens when the centripetal force is removed
- The relationship between tangential velocity and circular motion
- Why "centrifugal force" is *not* a real force in an inertial reference frame

Explain precisely why the ball's motion after release appears so different to the astronaut versus the ground observer.

Step C: Quantitative Setup

Now, and only now, write down the relevant equations. Define all variables clearly.

1. Write the relationship between angular velocity ω, tangential velocity v_t, and radius r.
2. Write the expression for centripetal acceleration a_c in terms of: (a) v_t and r, and (b) ω and r.
3. Write the expression for centripetal force F_c in terms of mass m and centripetal acceleration.
4. If the centrifuge completes one full rotation every 4 seconds, calculate the angular velocity in rad/s. **Do not complete further calculations yet.**

Part 3: 15 mins - Precise Execution

Calculation

The Decisive Calculation:
Using the following values:

- Radius of centrifuge arm: $r = 8.0$ m
- Period of rotation: $T = 4.0$ s
- Mass of ball: $m = 0.50$ kg

Calculate:

1. The angular velocity ω of the centrifuge in rad/s
2. The tangential velocity v_t of the ball just before release in m/s
3. The centripetal acceleration a_c the ball was experiencing before release (express as a multiple of $g = 9.8$ m/s^2)
4. The centripetal force that the astronaut's hand was exerting on the ball before release
5. The speed and direction of the ball immediately after release, as measured by the ground observer

Show all steps clearly and include units throughout.

The Check:
Once you have your numerical answers:

1. Revisit your Part 1 prediction about the ball's path. Was it correct for the ground observer? Was it correct for the astronaut?
2. In one sentence, state why the ball travels in a straight line after release (ground frame) despite the astronaut perceiving it to curve outward.
3. Calculate how far the ball would travel in a straight line during the time it takes the centrifuge to complete one-quarter of a rotation. Compare this to the arc length the astronaut travels in the same time.

Part 4: 10 mins - Reflection

Reflection & Integration

Reflection Prompts:

1. What was the key misconception this exercise was designed to expose? Many students believe that objects in circular motion have an outward "centrifugal force" acting on them. How does this exercise demonstrate why that mental model is problematic, and how will you correct your thinking going forward?
2. How did the process of drawing the free-body diagrams (Part 2, Step A) change or clarify your understanding compared to just reading the problem? Specifically, what did you learn from comparing the forces *before* and *after* release?
3. **Exam Link:** Find a past paper question involving an object on a string being whirled in a horizontal or vertical circle. Identify which part of that problem tests the same core insight about what provides centripetal force and what happens when that force is removed. How is this insight "disguised" in the standard problem format?
4. **Extension Thinking:** If the centrifuge were oriented vertically (like a Ferris wheel), how would the analysis change? At which point in the rotation would the astronaut feel "heaviest"? "Lightest"? Why?

The Takeaway:
Formulate a single, powerful "rule of thumb" or statement that encapsulates the lesson from this exercise. Your statement should capture the relationship between centripetal force, circular motion, and what happens when the force is removed.
Example format: "An object in circular motion requires [what?] directed [where?]. Without this, the object will [do what?] because [why?]."

Solutions for Part 3:

1. Angular velocity:

$$\omega = \frac{2\pi}{T} = \frac{2\pi}{4.0 \text{ s}} = \frac{\pi}{2} \text{ rad/s} \approx 1.57 \text{ rad/s}$$

2. Tangential velocity:

$$v_t = \omega r = \left(\frac{\pi}{2} \text{ rad/s}\right)(8.0 \text{ m}) = 4\pi \text{ m/s} \approx 12.6 \text{ m/s}$$

3. Centripetal acceleration:

$$a_c = \frac{v_t^2}{r} = \frac{(4\pi)^2}{8.0} = \frac{16\pi^2}{8.0} = 2\pi^2 \text{ m/s}^2 \approx 19.7 \text{ m/s}^2$$

As a multiple of g:

$$\frac{a_c}{g} = \frac{19.7}{9.8} \approx 2.0g$$

4. Centripetal force:

$$F_c = ma_c = (0.50 \text{ kg})(19.7 \text{ m/s}^2) \approx 9.9 \text{ N}$$

This is the inward force the astronaut's hand exerted on the ball.

5. Speed and direction after release:

- Speed: $v = v_t = 4\pi$ m/s ≈ 12.6 m/s (unchanged at instant of release)
- Direction: Tangent to the circle at point of release (perpendicular to the radius), in a straight line

The Check calculations:

- Time for quarter rotation: $t = T/4 = 1.0$ s
- Distance ball travels: $d = v_t \cdot t = 12.6 \times 1.0 = 12.6$ m (straight line)
- Arc length astronaut travels: $s = r\theta = 8.0 \times \frac{\pi}{2} = 4\pi \approx 12.6$ m

The ball and astronaut travel the same *distance* in this time, but the ball travels straight while the astronaut curves—this is why the ball appears to "fall behind" and move outward relative to the astronaut.

C. Calculation Error Analysis

Learning Focus: Developing **critical analysis skills** by identifying and correcting common physics **misconceptions** and **calculation errors** related to **circular motion**.

Analysis Tips

1. **Locate the Error:** Is there anything wrong with this statement/calculation?
2. **Diagnose the Error:** Is this a **Procedural Error** (miscalculation), a **Conceptual Error** (misunderstanding), or an **Omission Error** (incomplete answer)?
3. **Explain the Misconception:** What does the answer reveal about their understanding of how to *communicate* this idea?
4. **Correct the Solution:** Provide the complete, textbook-quality answer.
5. **Metacognitive Reflection:** "This error is subtle because the number is right. What is one personal strategy I can adopt to ensure I never overlook a crucial detail like this under exam pressure? (e.g., always underlining vector directions in the question if you often forget about directions)."

Forensic Physics Task

Your job isn't to find the right answer, but to find the **flaw in the thinking**. Explain ***why*** each statement/calculation is wrong and **correct them**.

Essential Circular Motion Formulas

- Radian definition: $\theta = \frac{s}{r}$
- Angular velocity: $\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi}{T}$
- Tangential velocity: $v = r\omega = \frac{2\pi r}{T}$
- Period-frequency: $T = \frac{1}{f}$
- Centripetal acceleration: $a_c = \frac{v^2}{r} = r\omega^2$
- Centripetal force: $F_c = \frac{mv^2}{r} = mr\omega^2$
- Degrees to radians: $\theta_{rad} = \theta_{deg} \times \frac{\pi}{180}$
- Full circle: 2π rad = 360ř

Error Analysis Exercises

Statement: "An object moving in a circle at constant speed has no acceleration because its speed isn't changing."

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Statement: ”The centrifugal force pushes an object outward when it moves in a circle.”

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Statement: ”If a string holding a ball in circular motion suddenly breaks, the ball will fly outward, away from the center of the circle.”

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Angle Conversion: Convert 45° to radians.
Incorrect Calculation: 45ř $= 45 \times \pi = 141.4$ rad

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Angular Velocity: A wheel completes 10 revolutions in 5 seconds. Calculate the angular velocity.
Incorrect Calculation: $\omega = \dfrac{10}{5} = 2$ rad/s

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Tangential Velocity: A point on a rotating disc is 0.5 m from the center. The disc rotates at 4 rad/s. Find the tangential velocity.

Incorrect Calculation: $v = \frac{\omega}{r} = \frac{4}{0.5} = 8$ m/s

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Centripetal Acceleration: A car travels around a circular track of radius 50 m at 20 m/s. Calculate the centripetal acceleration.

Incorrect Calculation: $a_c = \frac{v}{r} = \frac{20}{50} = 0.4$ m/s^2

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Centripetal Force: A 2.0 kg ball on a string moves in a horizontal circle of radius 1.5 m at 3.0 m/s. Calculate the centripetal force.

Incorrect Calculation: $F_c = \frac{mv^2}{r} = \frac{2.0 \times 3.0^2}{1.5} = \frac{2.0 \times 9.0}{1.5} = 12$ N outward

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Period and Frequency: A merry-go-round completes one rotation every 8 seconds.

Calculate its angular velocity.
Incorrect Calculation: $\omega = \frac{2\pi}{T} = \frac{2 \times 3.14}{8} = \frac{6.28}{8} = 0.785$ rev/s

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Arc Length: A pendulum of length 0.80 m swings through an angle of 30°. Calculate the arc length traveled by the bob.
Incorrect Calculation: $s = r\theta = 0.80 \times 30 = 24$ m

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Comparing Points on a Rotating Object: Two points A and B are on a rotating disc. Point A is 10 cm from the center and point B is 20 cm from the center. A student claims: "Point B has twice the angular velocity of point A because it's twice as far from the center."

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Vertical Circular Motion: A roller coaster car of mass 500 kg travels through a vertical loop of radius 10 m. At the top of the loop, its speed is 14 m/s. Calculate the normal force on the car at the top.
Incorrect Calculation: $F_c = \frac{mv^2}{r} = \frac{500 \times 14^2}{10} = 9800$ N
Therefore, the normal force = 9800 N

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Banked Curve: A car travels around a frictionless banked curve of radius 100 m at 25 m/s. A student calculates the banking angle needed:
Incorrect Calculation: "The centripetal force equals the weight component, so:"

$$\frac{mv^2}{r} = mg\sin\theta$$

$$\tan\theta = \frac{v^2}{gr} = \frac{25^2}{9.8 \times 100} = 0.638$$

$$\theta = 32.5ř$$

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Satellite Orbital Velocity: Calculate the orbital velocity of a satellite orbiting Earth at a height of 400 km above the surface. ($R_{Earth} = 6.37 \times 10^6$ m, $g = 9.8$ m/s^2)
Incorrect Calculation: Using $v = \sqrt{gR}$

$$v = \sqrt{9.8 \times 400,000} = \sqrt{3.92 \times 10^6} = 1980 \text{ m/s}$$

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Conical Pendulum: A 0.50 kg ball attached to a 1.2 m string swings in a horizontal circle, making an angle of 30° with the vertical. Calculate the tension in the string.
Incorrect Calculation: "The tension provides the centripetal force, so:"

$$T = \frac{mv^2}{r}$$

Since the ball hangs at 30°, $T = mg\cos(30ř) = 0.50 \times 9.8 \times 0.866 = 4.24$ N

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Minimum Speed in Vertical Circle: Find the minimum speed at the top of a vertical loop of radius 5.0 m so that a roller coaster maintains contact with the track.
Incorrect Calculation: "At minimum speed, the centripetal force equals zero:"

$$\frac{mv^2}{r} = 0$$

Therefore, $v = 0$ m/s

Flawed Thinking

Error Analysis:

Correct Approach

Correction:

Reflection Time

You have seen some of the common errors and misconceptions that come up in circular motion. Here are some important questions to **ask yourself**:

- **What surprised you about the relationship between speed and velocity in circular motion? *Why*?**
- **Which formula did you find most confusing to apply correctly? *Why*?**
- **Did you initially believe in "centrifugal force"? How has your understanding changed?**
- **What strategy will you use to remember that angular velocity is the same for all points on a rigid rotating body?**

Exercise D1: Revision of Foundational Skills - Units, Dimensions & Significant Figures

1. SI Base Units and Derived Units

a) State the seven SI base quantities and their corresponding SI base units with symbols.
b) Express the following derived units in terms of SI base units:

i) Newton (N)
ii) Joule (J)
iii) Watt (W)
iv) Pascal (Pa)
v) Volt (V)
vi) Ohm (Ω)

c) What is the difference between a base unit and a derived unit? Give two examples of each.
d) Define the following SI prefixes and express them as powers of 10: mega, micro, nano, giga, pico, kilo.

2. Dimensional Analysis

a) Write the dimensions of the following quantities using $[M]$, $[L]$, $[T]$, $[I]$, $[K]$, $[N]$, [mol]:

i) Velocity
ii) Acceleration
iii) Force
iv) Energy
v) Pressure
vi) Power
vii) Momentum
viii) Electric charge

b) Use dimensional analysis to check whether the following equations are dimensionally consistent:
i) $v = u + at$
ii) $s = ut + \frac{1}{2}at^2$
iii) $E = mc^3$ *(Is this correct?)*
iv) $T = 2\pi\sqrt{\frac{l}{g}}$ for a simple pendulum

c) The drag force on a sphere moving through a fluid is given by $F = kv^a r^b \rho^c$, where v is velocity, r is radius, and ρ is fluid density. Use dimensional analysis to find a, b, and c.
d) A student claims that kinetic energy is given by $E_k = \frac{1}{2}mv^3$. Use dimensional analysis to show this is incorrect.

3. Unit Conversions

a) Convert 72.0 km/h to m/s
b) Convert 9.81 m/s^2 to km/h^2
c) Convert 1.50×10^{-3} g/mm^3 to kg/m^3
d) Convert 3.00×10^8 m/s to km/h
e) Convert 101 kPa to N/m^2
f) Convert 4.50 MJ to kWh
g) Convert 2.40×10^{-6} m^2 to mm^2
h) Convert 7.50 g/cm^3 to kg/m^3

4. Significant Figures

a) State the number of significant figures in each of the following:

i) 0.00340
ii) 2.500×10^3
iii) 1000
iv) 1000.
v) 0.0102
vi) 6.022×10^{23}

b) Perform the following calculations and express your answer to the appropriate number of significant figures:

i) 3.14×2.1
ii) $\frac{4.56}{1.2}$
iii) $12.34 + 1.2$
iv) $6.63 \times 10^{-34} \times 3.00 \times 10^8$
v) $(2.50)^3$
vi) $\sqrt{144.0}$

c) Explain the difference between precision and accuracy. A student measures a length as 5.23 m, 5.25 m, 5.24 m, 5.24 m when the true value is 5.00 m. Comment on the precision and accuracy.

d) Why is it incorrect to write a final answer as 2.456789 m/s when your initial measurements had only 3 significant figures?

5. DST Triangle and Basic Kinematics Formulae

a) Draw and label the DST (Distance-Speed-Time) triangle. Write out the three formulae it represents.

b) A car travels 156 km in 2.40 hours. Calculate the average speed in:
   i) km/h
   ii) m/s

c) Sound travels at approximately 343 m/s in air. How long does it take for sound to travel 1.50 km?

d) Light takes 8.32 minutes to travel from the Sun to Earth. If the speed of light is 3.00×10^8 m/s, calculate the Earth-Sun distance in km.

e) A train travels at 25.0 m/s. How far does it travel in 45.0 minutes?

Exercise D2: Application & Reasoning - Units, Dimensions & Significant Figures

6. Deriving Units from Equations: For each equation, determine the SI unit of the unknown quantity:

a) $F = ma$, find the unit of F if m is in kg and a is in m/s^2.
b) $E = \frac{1}{2}mv^2$, verify the unit of energy.
c) $P = \frac{W}{t}$, where W is in joules and t is in seconds.
d) $\rho = \frac{m}{V}$, where m is in kg and V is in m^3.

7. Dimensional Analysis - Deriving Relationships: The period T of a simple pendulum depends on its length l and the acceleration due to gravity g.

- Using dimensional analysis, show that $T \propto \sqrt{\frac{l}{g}}$.
- If a pendulum has length 1.20 m and $g = 9.81$ m/s^2, calculate the period using $T = 2\pi\sqrt{\frac{l}{g}}$.
- Express your answer to 3 significant figures and explain why this number of significant figures is appropriate.

8. Checking Physical Equations: A student proposes the following equations for physical quantities. Use dimensional analysis to determine which are dimensionally valid:

a) $v^2 = u^2 + 2as$
b) $F = \frac{mv^2}{r}$ (centripetal force)
c) $E = mgh + \frac{1}{2}mv$ *(Find the error)*
d) $P = \rho gh$ (pressure at depth h in a fluid)

For any incorrect equation, identify the dimensional inconsistency.

9. Multi-Step Unit Conversion Problem: A car's fuel efficiency is rated at 8.50 L per 100 km.

- Convert this to gallons per mile (1 gallon = 3.785 L, 1 mile = 1.609 km).
- Express this alternatively as miles per gallon (mpg).
- Comment on why different countries use different conventions for fuel efficiency.

10. Error Propagation and Significant Figures: A rectangular block has measured dimensions:

- Length: $l = 12.5 \pm 0.1$ cm
- Width: $w = 8.40 \pm 0.05$ cm
- Height: $h = 3.20 \pm 0.02$ cm

a) Calculate the volume of the block.
b) Express your answer to the appropriate number of significant figures.
c) Explain why the final answer cannot have more significant figures than the least precise measurement.

11. Real-World DST Application: An athlete runs a marathon (42.2 km) in 2 hours 45 minutes and 30 seconds.

- Convert the time to hours (as a decimal to 3 s.f.).
- Calculate the average speed in m/s and km/h.
- The athlete's speed varied during the race: 5.00 m/s for the first half, then 3.80 m/s for the second half. Calculate the total time for the race with these speeds and compare to the actual time.
- Explain why average speed is not simply $\frac{5.00+3.80}{2}$ m/s.

12. Dimensional Analysis - Finding Unknown Powers: The escape velocity v of a planet depends on its mass M, its radius R, and the gravitational constant G (with units $\text{N}\cdot\text{m}^2/\text{kg}^2$).

- Express the dimensions of G in terms of $[M]$, $[L]$, and $[T]$.
- Assuming $v = kG^aM^bR^c$ where k is dimensionless, use dimensional analysis to find a, b, and c.
- Given that $G = 6.67 \times 10^{-11}$ $\text{N}\cdot\text{m}^2/\text{kg}^2$, Earth's mass $M = 5.97 \times 10^{24}$ kg, and Earth's radius $R = 6.37 \times 10^6$ m, calculate the escape velocity (the actual formula is $v = \sqrt{\frac{2GM}{R}}$).

13. Critical Thinking - Significant Figures in Context:

- A physics experiment yields the result $g = 9.7843621$ m/s^2 from a stopwatch with ± 0.1 s precision and a ruler with ± 1 mm precision. Explain why reporting all these digits is inappropriate.
- In what situations might you deliberately use fewer significant figures than your data allows?
- A student argues that π should be written as 3.14159265... in all calculations. Critique this statement in the context of experimental physics.

Exercise E: Past Exam Experiment Practice

Complete all Section A questions from the 2025 HL Physics exam. Attempt each one from memory first, then use your book to finish them off if needed. FInally, compare your work with the marking scheme.

Self-Assessment

After completing the assessment:

- Grade your work honestly
- Identify areas needing improvement
- Scan and submit via Google Classroom
- Reflect on your performance in your weekly reflection

Another excellent week of work completed - ***well done!*** You are another step closer to *smashing your exams*, and another week closer to your summer holdiays!

Weekly Reflection Zone

What worked well this week?

What challenges did I face?

What surprised me the most this week?

Key physics concepts I want to review:

Goals for next week: