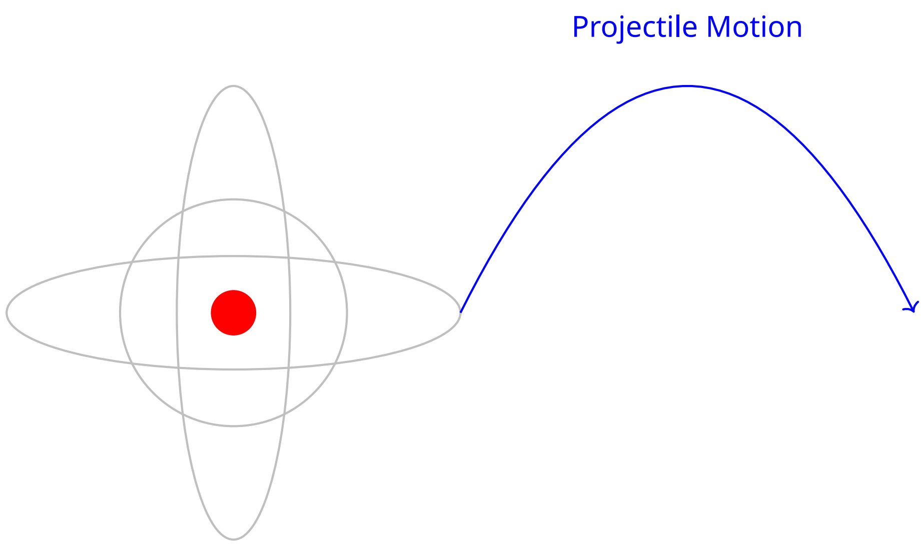
Physics Instructional Material

Grade 10: Scientific Inquiry and Curved Motion



Synthesized for Academic Excellence
Based on National Curriculum Standards

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Contents

1 The Nature of Physics and Scientific Inquiry

Physics is the most fundamental natural science, exploring the basic constituents of the universe and the forces acting upon them. It bridges the gap between raw natural observations and structured mathematical laws.

1.1 The Scientific Process in Physics

Physical knowledge is built upon a cycle of inquiry that ensures results are reproducible and verifiable.

- **Observation:** Using instruments to extend human senses beyond their natural limits.
- **Hypothesis:** Proposing a logical explanation based on existing physical laws.
- **Experimentation:** Testing the hypothesis under controlled conditions to isolate variables.
- **Model Creation:** Synthesizing results into mathematical equations or conceptual frameworks.

1.2 Historical Development

The evolution of physics is broadly categorized into two eras:

1. **Classical Physics (Pre-1900):** Concerned with macroscopic phenomena. Key figures include *Isaac Newton* (Mechanics), *James Clerk Maxwell* (Electromagnetism), and *Ludwig Boltzmann* (Thermodynamics).
2. **Modern Physics (Post-1900):** Explains subatomic particles and high-velocity systems. The pillars are *Quantum Mechanics* and *General Relativity*.

2 The International System of Units (SI)

To ensure clarity in international scientific communication, the SI system defines standard units for every physical quantity.

2.1 The Seven Base Units

All measurements are derived from these seven fundamental quantities:

2.2 Scientific Prefixes

Prefixes simplify the reporting of scale:

- **Giga (G):** 10^9 (e.g., Gigahertz)
- **Kilo (k):** 10^3 (e.g., Kilometer)

Table 1: SI Base Units

Quantity	Symbol	Unit Name	Symbol
Length	l, x	Meter	m
Mass	m	Kilogram	kg
Time	t	Second	s
Electric Current	I	Ampere	A
Temperature	T	Kelvin	K
Amount of Substance	n	Mole	mol
Luminous Intensity	I_v	Candela	cd

- **Milli (m):** 10^{-3} (e.g., Millimeter)
- **Nano (n):** 10^{-9} (e.g., Nanosecond)

3 Precision and Significant Figures

In science, no measurement is exact. The way we record numbers indicates the precision of the instrument used.

3.1 Rules for Significant Figures

Significant figures include all certain digits plus one estimated digit.

1. All non-zero digits are always significant.
2. Zeros between significant digits are significant (e.g., 105 has 3).
3. Leading zeros are **not** significant (e.g., 0.002 has 1).
4. Trailing zeros are significant **only** if a decimal point is present (e.g., 120.0 has 4; 120 has 2).

3.2 Mathematical Operations

- **Addition/Subtraction:** The result matches the measurement with the fewest *decimal places*.
- **Multiplication/Division:** The result matches the measurement with the fewest *total significant figures*.

4 Uncertainty in Measurements

Uncertainty (Δx) defines the range within which the true value likely lies.

4.1 Types of Errors

- **Systematic Errors:** Predictable deviations caused by uncalibrated equipment or experimental bias. These affect *accuracy*.
- **Random Errors:** Unpredictable variations caused by environmental changes or human reaction time. These affect *precision*.

4.2 Reporting Results

Data is reported as: Result $= \bar{x} \pm \Delta\bar{x}$. Where the uncertainty $\Delta\bar{x}$ for a data set is:

$$\Delta\bar{x} = \frac{x_{max} - x_{min}}{2}$$

5 Experimental Data Analysis

Plotting data on a Cartesian coordinate system allows scientists to visualize relationships.

5.1 The Linear Equation

The slope (m) of a linear graph usually represents a physical constant:

$$m = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1}$$

5.2 Linearization of Data

Some relationships are non-linear. For a pendulum, $T = 2\pi\sqrt{l/g}$. Squaring both sides yields:

$$T^2 = \left(\frac{4\pi^2}{g}\right) l$$

By plotting T^2 (y-axis) against l (x-axis), the slope $m = 4\pi^2/g$, allowing us to solve for g.

6 Two-Dimensional Motion: Projectile Motion

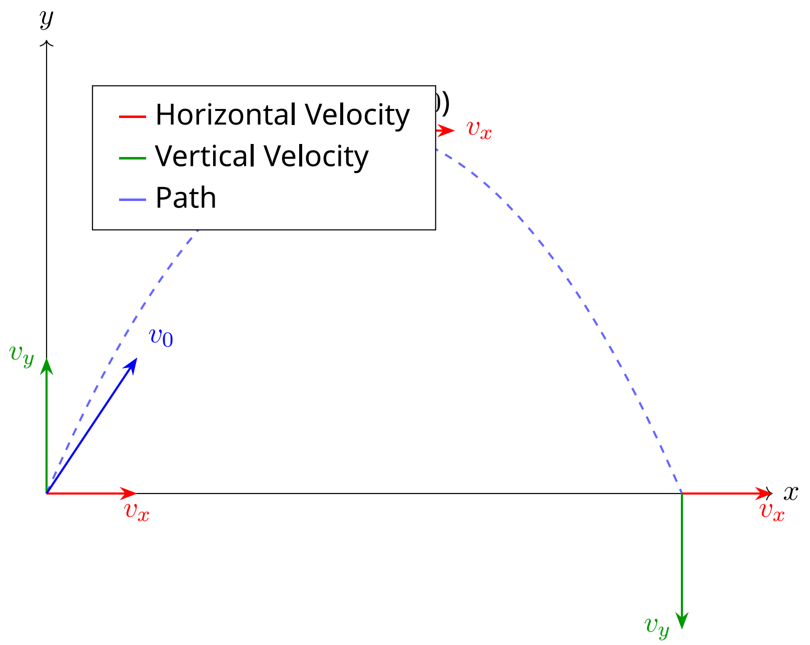
Projectile motion is the motion of an object thrown or projected into the air, subject only to the acceleration of gravity.

6.1 Principles of Projectile Motion

- **Independence of Motion:** Horizontal and vertical components are independent.
- **Horizontal Component:** Constant velocity ($a_x = 0$) because no horizontal force acts on the projectile (ignoring air resistance).
- **Vertical Component:** Constant acceleration ($a_y = -g = -9.8$ m/s^2) due to gravity.

6.2 TikZ Illustration: Projectile Trajectory

The following diagram illustrates the vector components of a projectile at various points along its path.



6.3 Kinematic Equations for Projectiles

For a projectile launched with initial velocity u at angle θ:

- **Initial Components:** $u_x = u\cos\theta$, $u_y = u\sin\theta$
- **Horizontal Displacement:** $\Delta x = u_x t$
- **Vertical Displacement:** $\Delta y = u_y t - \frac{1}{2}gt^2$
- **Vertical Velocity:** $v_y = u_y - gt$

7 Circular Motion

Circular motion occurs when an object travels along a circular path.

7.1 Uniform Circular Motion (UCM)

In UCM, the object travels at a constant *speed*, but its *velocity* is constantly changing because its direction is changing. This requires a centripetal force.

- **Centripetal Acceleration (a_c):** Always directed toward the center.

$$a_c = \frac{v^2}{r} = \omega^2 r$$

- **Centripetal Force (F_c):** The net force required to maintain circular motion.

$$F_c = ma_c = \frac{mv^2}{r}$$

7.2 Angular Kinematics

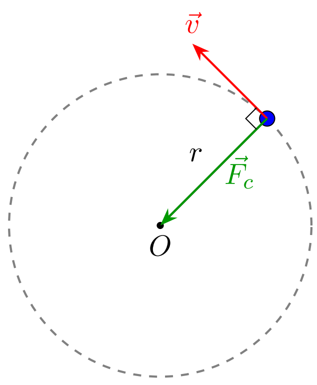
- **Angular Speed (ω):** The rate of change of the angle (θ).

$$\omega = \frac{\Delta\theta}{\Delta t} \text{ (rad/s)}$$

- **Relationship to Linear Speed:** $v = \omega r$
- **Period (T):** Time for one full revolution. $T = \frac{2\pi}{\omega} = \frac{2\pi r}{v}$

7.3 TikZ Illustration: Uniform Circular Motion

The diagram below shows the perpendicular relationship between velocity and centripetal force.



8 Applications of Circular Motion

8.1 Motion on Curved Roads

When a car turns on a flat road, static friction between the tires and the road provides the centripetal force:

$$f_s = F_c \implies \mu_s mg = \frac{mv^2}{r} \implies v_{max} = \sqrt{\mu_s gr}$$

To increase safety, roads are often "banked" (tilted).

8.2 Satellite Motion

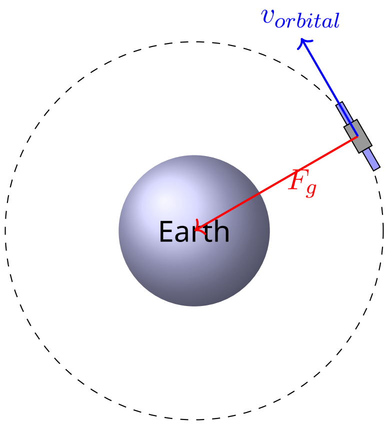
For a satellite of mass m orbiting a planet of mass M at radius r, gravity acts as the centripetal force:

$$G\frac{Mm}{r^2} = \frac{mv^2}{r}$$

Solving for orbital velocity v:

$$v = \sqrt{\frac{GM}{r}}$$

8.3 TikZ Illustration: Satellite Orbit



9 Worked Examples

9.1 Example 1: Projectile Calculation

Problem: A ball is kicked from the ground with an initial velocity of 20 m/s at an angle of $30°$. Find the time of flight and the maximum height.

Solution: 1. *Initial Vertical Velocity:*

$$u_y = 20\,\text{sin}(30°) = 20 \times 0.5 = 10 \text{ m/s}$$

2. *Time to peak ($v_y = 0$):*

$$0 = u_y - gt \implies t = \frac{10}{9.8} \approx 1.02 \text{ s}$$

3. *Total Time of Flight:*

$$T = 2 \times 1.02 = 2.04 \text{ s}$$

4. *Maximum Height:*

$$\Delta y = u_y t - \frac{1}{2}gt^2 = 10(1.02) - 0.5(9.8)(1.02)^2 \approx 5.1 \text{ m}$$

9.2 Example 2: Centripetal Acceleration

Problem: A stone of mass 0.5 kg is whirled in a horizontal circle of radius 2.0 m with a frequency of 5 Hz. Calculate the centripetal force.

Solution: 1. *Angular Speed (ω):*

$$\omega = 2\pi f = 2 \times 3.14 \times 5 = 31.4 \text{ rad/s}$$

2. *Centripetal Acceleration (a_c):*

$$a_c = \omega^2 r = (31.4)^2 \times 2.0 \approx 1972 \text{ m/s}^2$$

3. *Centripetal Force (F_c):*

$$F_c = m a_c = 0.5 \times 1972 = 986 \text{ N}$$

9.3 Example 3: Uncertainty Reporting

Problem: A student measures the diameter of a wire five times: $1.22, 1.25, 1.19, 1.23, 1.21$ mm. Report the final result with uncertainty.

Solution: 1. *Average ($\bar{x}$):*

$$\bar{x} = \frac{1.22 + 1.25 + 1.19 + 1.23 + 1.21}{5} = 1.22 \text{ mm}$$

2. *Uncertainty ($\Delta\bar{x}$):*

$$\Delta\bar{x} = \frac{1.25 - 1.19}{2} = 0.03 \text{ mm}$$

3. *Report:* 1.22 ± 0.03 mm

10 Review Exercises

1. **Unit Conversion:** An athlete runs at a speed of 12 m/s. Convert this to km/h.
2. **Significant Figures:** State the number of significant figures in the following:
   - 0.00450
   - 100.01
   - 6.022×10^{23}
3. **Analysis:** A graph of Velocity (v) vs Time (t) follows the equation $v = 4.5t + 2.0$.
   - What physical quantity does the slope (4.5) represent?
   - What was the initial velocity of the object?
4. **Projectile Motion:** A stone is thrown horizontally from a cliff 45 m high with a speed of 15 m/s.
   - How long does it take to reach the ground?
   - How far from the base of the cliff does it land?
5. **Circular Motion:** A car enters a circular curve of radius 50 m at a speed of 20 m/s.
   - Calculate the centripetal acceleration.
   - If the mass of the car is 1000 kg, what is the required friction force?
6. **Challenge:** Prove that for a projectile launched from the ground, the range R is maximized when the launch angle $\theta = 45°$. (Hint: $R = \frac{u^2 \sin(2\theta)}{g}$).

— End of Unit Course Material —