TOPIC 1.5: CIRCULAR MOTION

S4P-1-19   Explain qualitatively why an object moving at constant speed in a circle is accelerating toward the centre of the circle.

S4P-1-20   Discuss the centrifugal effects with respect to Newton's laws.

S4P-1-21   Draw free-body diagrams of an object moving in uniform circular motion.

S4P-1-22   Experiment to determine the mathematical relationship between period and frequency and one or more of the following: centripetal force, mass, and radius.

S4P-1-23   Derive an equation for the constant speed and acceleration of an object moving in a circle

$$\left(\vec{v} = \frac{2\pi r}{T}, \ a = \frac{v^2}{R} \right).$$

S4P-1-24   Solve problems for an object moving with a constant speed in a circle using

$$a = \frac{v^2}{R}, \ \vec{v} = \frac{2\pi r}{T}, \ \text{and} \ \vec{F}_{\text{net}} = m\vec{a}.$$

GENERAL LEARNING OUTCOME CONNECTION	SPECIFIC LEARNING OUTCOME
Students will…	**S4P-1-19: Explain qualitatively why an object moving at a constant speed in a circle is accelerating toward the centre of the circle.**
Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)	

## SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Students should be familiar with the circumference of a circle, Newton's Second Law, and uniform accelerated motion.

Notes to the Teacher

Uniform circular motion is the motion of an object moving at a constant speed in a circular path. The acceleration—centripetal acceleration—toward the centre of the circle can be explained using the definition of acceleration (rate of change of velocity) where the direction of the acceleration is the same as the direction of the change in velocity (see diagram). That is, since the net force is toward the centre, so is the acceleration.

Classroom Activities

Students build and use accelerometers to observe the effects of various forms of acceleration. These devices are often used when students investigate the physics of amusement park rides.
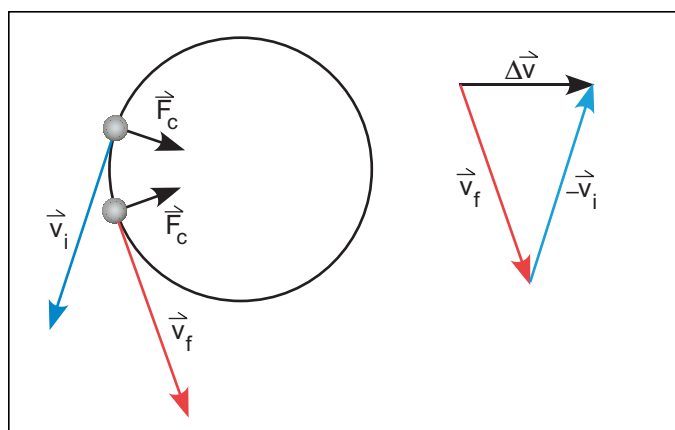
SKILLS AND ATTITUDES OUTCOME

S4P-0-2a: Select and use appropriate
visual, numeric, graphical, and
symbolic modes of representation
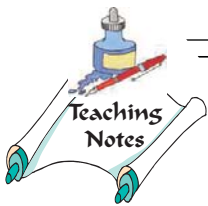to identify and represent
relationships.

**GENERAL LEARNING OUTCOME
CONNECTION**

Students will…

Demonstrate curiosity, skepticism,
creativity, open-mindedness, accuracy,
precision, honesty, and persistence, and
appreciate their importance as scientific
and technological habits of mind
(GLO C5)

SUGGESTIONS FOR INSTRUCTION

Teaching
Notes

SUGGESTIONS FOR ASSESSMENT

GENERAL LEARNING OUTCOME CONNECTION	SPECIFIC LEARNING OUTCOME
Students will…	**S4P-1-20: Discuss the centrifugal effects with respect to Newton's laws.**
Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life (GLO C8)	

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Newton's laws are covered in Senior 2 Science and Senior 3 Physics.

Notes to the Teacher

If you are in the front seat of a car and the car suddenly turns in a circular path, counterclockwise, you will be "thrown" to the right-hand side of the car. You will feel as if there is a force moving you. Such a force, which appears to be directed away from the centre of the path, is often called a centrifugal "force." As the car moves in a circular path, inertia keeps your body going in a straight line. This path causes you to move to the right-hand side of the car, which is turning. The centrifugal "force" feels real, but it doesn't really exist. Consequently, most physicists prefer the term "centrifugal effect" rather than "centrifugal force."

Often, this outward force is attributed to circular motion. For example, everything on a rotating platform behaves as if there was a mysterious force pulling outwards. Tall objects tend to topple over and small ones try to slide away from the centre. Some people refer to this as centrifugal "force," but there really is no force at all. Centrifugal means "centre-fleeing" or "away from the centre." Centrifugal "force" can be explained by the absence of a force to keep the object moving in circular motion. If an object in uniform circular motion is suddenly released, the object will move off in a straight line at a constant speed according to Newton's Law of Inertia. Sometimes, it is useful to use a frame of reference that is rotating with the system. In such a system, the centrifugal "force" appears mathematically. But, when the same situation is examined from a stationary frame, such as the ground, it does not exist.

SKILLS AND ATTITUDES OUTCOME

S4P-0-4e: Demonstrate a continuing and more informed interest in science and science-related issues.

SUGGESTIONS FOR INSTRUCTION	SUGGESTIONS FOR ASSESSMENT

Classroom Activities

Have students predict the path of an object moving in uniform circular motion when it is suddenly released. The object could be attached to the end of string or a marble rolling around the inside of a ice cream pail lid with one portion of the lid removed.
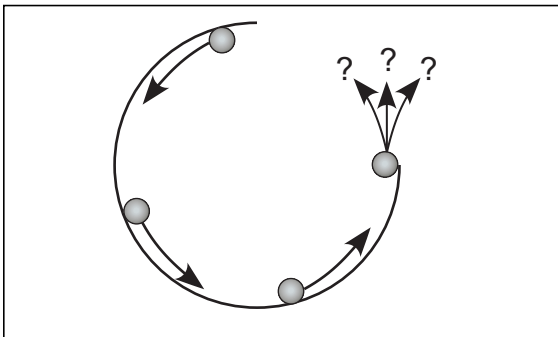
Demonstration

A centrifuge is a useful device for separating substances; for example, a cream separator on a farm or a blood centrifuge in the hospital. A simple centrifuge can be made with an old turntable, some cups, and some objects such as ping pong balls (see Appendix 1.9 for details).

GENERAL LEARNING OUTCOME CONNECTION	SPECIFIC LEARNING OUTCOME	SKILLS AND ATTITUDES OUTCOMES
Students will…	**S4P-1-21: Draw free-body diagrams of an object moving in uniform circular motion.**	**S4P-0-2h:** Analyze problems using vectors.
Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)		Include: Adding and subtracting vectors in straight lines, at right angles, and at non-orthogonal angles

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Free-body diagrams are covered in Senior 3 Physics.

Notes to the Teacher

Students can draw free-body diagrams to illustrate forces acting on a sphere or a coin moving in a uniform circular motion. In each case, they should indicate the force(s) responsible for the centripetal force. The relative length of the vectors corresponding to the forces should be drawn to scale.
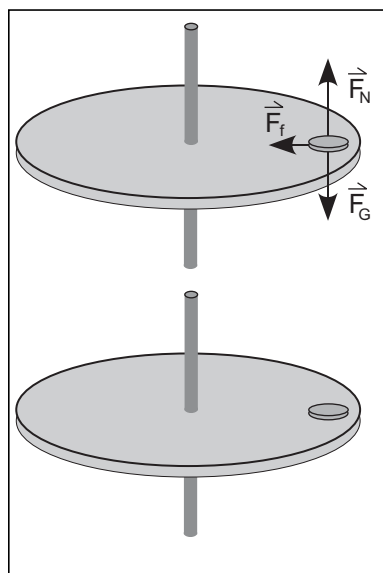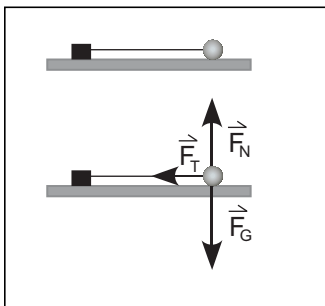
Symbols:

F_g — Weight F_T — Tension

F_f — Friction F_N — Normal Force

F_C — Centripetal Force

Rotating Coin

Rotating Sphere

SKILLS AND ATTITUDES OUTCOMES

S4P-0-2i: Select and integrate information obtained from a variety of sources.

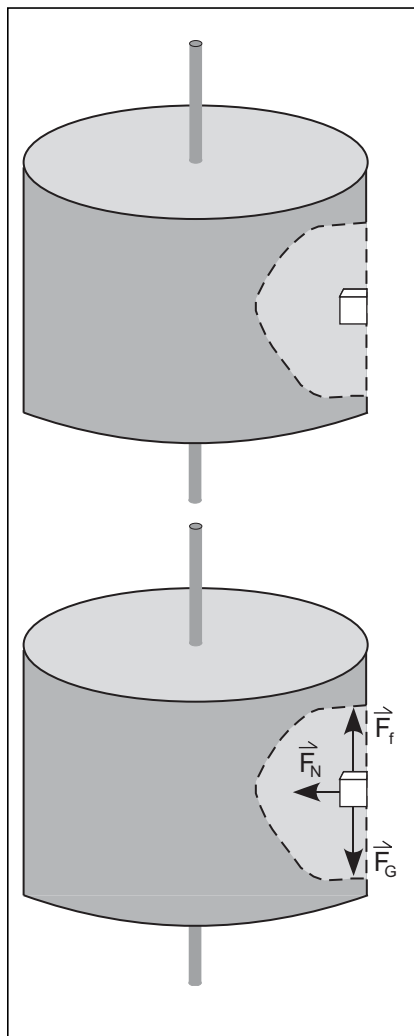Include: print, electronic, specialists, or other resource people

S4P-0-4b: Work co-operatively with a group to identify prior knowledge, initiate and exchange ideas, propose problems and their solution, and carry out investigations.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Demonstrate appropriate scientific inquiry skills when seeking answers to questions (GLO C2)

SUGGESTIONS FOR INSTRUCTION

SUGGESTIONS FOR ASSESSMENT

Visual Displays

Students design and construct a model of an amusement park ride. The forces acting are described using a free-body diagram.

Rotating Cylinder

SUGGESTED LEARNING RESOURCES

Going in Circles, Activity 30, p 183, Lab Manual, *Conceptual Physics*, Pearson, 2002

| GENERAL LEARNING OUTCOME CONNECTION	SPECIFIC LEARNING OUTCOME	SKILLS AND ATTITUDES OUTCOMES
Students will… Demonstrate appropriate problem-solving skills while seeking solutions to technological challenges (GLO C3)	**S4P-1-22: Experiment to determine the mathematical relationship between period and frequency and one or more of the following: centripetal force, mass, and radius.**	**S4P-0-1e:** Differentiate between how scientific theories explain natural phenomena and how scientific laws identify regularities and patterns in nature. **S4P-0-2a:** Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

SUGGESTIONS FOR INSTRUCTION

Entry Level Knowledge

Students have used graphical analysis to investigate mostly linear relationships. In this case, graphical analysis is extended to the power and inverse relationships.

Notes to the Teacher

The common approach to investigating the relationships for circular motion is by swinging a rubber stopper as shown in the diagram. Several factors can be measured, including frequency, period, mass, radius, and force.
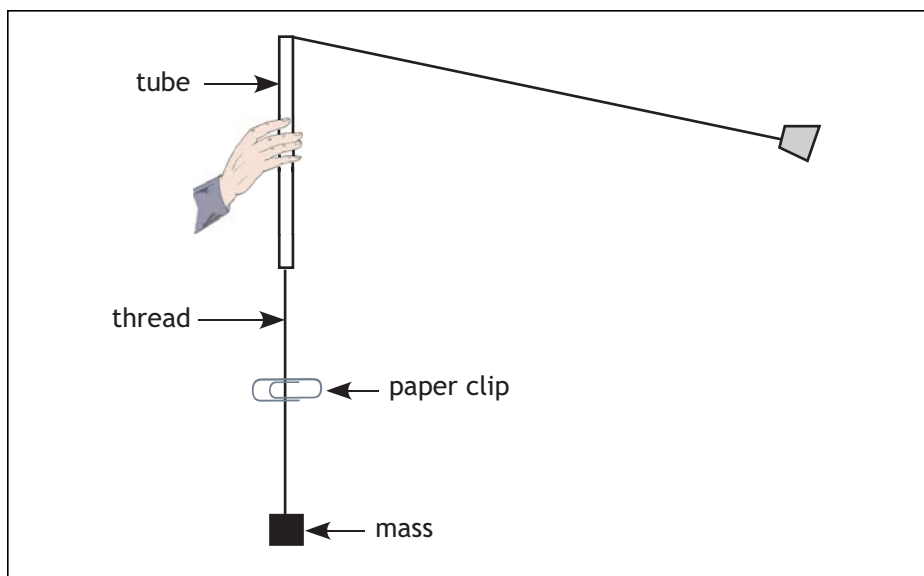
SKILLS AND ATTITUDES OUTCOMES

S4P-0-2b: Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required.

S4P-0-2c: Formulate operational definitions of major variables or concepts.

S4P-0-2d: Estimate and measure accurately using SI units.

S4P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data-collection methods.

Include: discrepancies in data and sources of error

S4P-0-2f: Record, organize, and display data using an appropriate format.

Include: labelled diagrams, tables, graphs

S4P-0-2g: Develop mathematical models involving linear, power, and/or inverse relationships among variables.
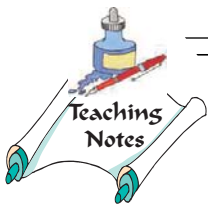
GENERAL LEARNING OUTCOME CONNECTION

Students will…

Work co-operatively and value the ideas and contributions of others while carrying out scientific and technological activities (GLO C7)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Laboratory Report

Students collect, organize, and graphically illustrate data obtained and submit a lab report.

SUGGESTED LEARNING RESOURCES

Investigation 11-B: Verifying the Circular Motion Equation, *Physics 12*, McGraw-Hill Ryerson, 2003

<table>
<tr><td>

G<small>ENERAL</small> L<small>EARNING</small> O<small>UTCOME</small> C<small>ONNECTION</small>

Students will…

Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop (GLO A2)

</td><td>

S<small>PECIFIC</small> L<small>EARNING</small> O<small>UTCOMES</small>

S4P-1-23: Derive an equation for the constant speed and acceleration of an object moving in a circle

$$\left(\vec{v} = \frac{2\pi r}{T},\ a = \frac{v^2}{R} \right).$$

S4P-1-24: Solve problems for an object moving with a constant speed in a circle using

$$a = \frac{v^2}{R},\ \vec{v} = \frac{2\pi r}{T},\ \text{and}\ \vec{F}_{net} = m\vec{a}.$$

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S<small>UGGESTIONS FOR</small> I<small>NSTRUCTION</small>

Notes to the Teacher

The equation for the constant speed of an object moving in a circle is derived from basic principles. We know that

$$v = \frac{\Delta d}{\Delta t}$$

and, for an object moving in a circle, that the path is the circumference of the circle. That is $\Delta d = 2\pi R$.

Therefore, $\vec{v} = \dfrac{2\pi r}{T}$.

There are several ways to derive $a = \dfrac{v^2}{R}$.

Remind students that vectors can be moved anywhere as long as the magnitude and direction do not change. Compare the triangles formed from the position vectors $\left(\Delta\vec{R} = \vec{R_2} - \vec{R_1} \right)$

and the velocity vectors $\left(\Delta\vec{v} = \vec{v_2} - \vec{v_1} \right)$.
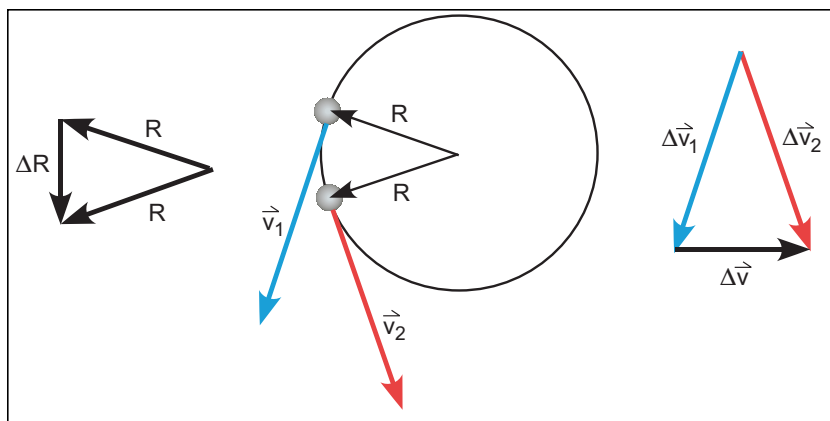
Since these triangles are similar, the ratio of the corresponding sides are equal and, $\dfrac{\Delta R}{R} = \dfrac{\Delta v}{v}$,

divide both sides by Δt to get $\dfrac{\Delta R}{R\Delta t} = \dfrac{\Delta v}{v\Delta t}$.

Since $v = \dfrac{\Delta R}{\Delta t}$ and $a = \dfrac{\Delta v}{\Delta t}$, this reduces to $\dfrac{v}{R} = \dfrac{a}{v}$

and finally $a = \dfrac{v^2}{R}$.

Notice this is a scalar equation; however, the direction of the acceleration will always be toward the centre of the circle.

SKILLS AND ATTITUDES OUTCOME

S4P-0-2g: Develop mathematical
models involving linear, power,
and/or inverse relationships
among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Demonstrate appropriate scientific
inquiry skills when seeking answers to
questions (GLO C2)

Understand how stability, motion, forces,
and energy transfers and transformations
play a role in a wide range of natural and
constructed contexts (GLO D4)

SUGGESTIONS FOR INSTRUCTION

Teaching
Notes

SUGGESTIONS FOR ASSESSMENT
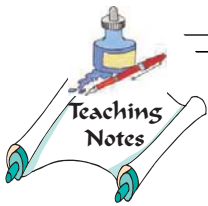
Students write process notes to outline the steps of
the derivations.

Given the diagram, students draw the similar
triangles and state the ratio of the corresponding
sides.

NOTES