Unit 1
Force, Motion, and Energy
Suggested Time: 43 Hours

Unit Overview

Introduction

From the first intelligent musings of the human species came questions which are answered in this unit. A rock falls or is thrown; the sun, moon, and stars move about in the heavens; a bird flies; fire consumes. Early civilizations explained the mysteries of the natural world with spiritual answers. By the Greco-Roman era, mathematics had advanced and more worldly theories were proposed.

But it was the Renaissance and the Galilean method of doing science that began the classical period in physical science. Concepts of force, momentum, and energy; precise observations of orbital motions; and a mathematical system to handle rates of change led to explanations that satisfied all ordinary experiences.

Focus and Context

At the beginning of the twenty-first century, we still live in a Newtonian world. Students should relate their study of mechanics to everyday occurrences. They should come to understand that the engineered world in which we live is built on the principles of classical physics. From skateboards to space shuttles, the causes and effects of motion are understood and applied. Activities and investigations of everyday events that are generated by class discussion should be encouraged. Students should have many opportunities to express their understanding of physics concepts, both verbally and in writing.

Science Curriculum Links

Students have previously studied forces and motion in Grade 7 (gravity, friction and Newton's 1st and 3rd laws). This study of motion continued in Science 1206, and expanded on Physics 2204 to include wave motion as well as the movement of solid objects. Students will use their ability to describe motion to move on to an understanding of the forces which *cause* motion. They will then apply this knowledge to interactions between objects. This is the conceptual framework on which students can build a wider understanding in post-secondary science studies.

Curriculum Outcomes

STSE

Students will be expected to

Relationships Between Science and Technology

116-4 analyse and describe examples where technologies were developed based on scientific understanding

116-7 analyse natural and technological systems to interpret and explain their structure and dynamics

Social and Environmental Contexts of Science and Technology

117-2 analyse society's influence on scientific and technological endeavours

118-8 distinguish between questions that can be answered by science and those that cannot and between problems that can be solved by technology and those that cannot

Skills

Students will be expected to

Initiating and Planning

212-1 identify questions to investigate that arise from practical problems and issues

212-2 define and delimit problems to facilitate investigation

212-3 design an experiment identifying and controlling major variables

Performing and Recording

213-4 estimate quantities

213-3 use instruments effectively and accurately for collecting data

Analysing and Interpreting

214-3 compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots

214-5 interpret patterns and trends in data, and infer or calculate linear and non-linear relationships among variables

214-14 construct and test a prototype of a device or system and troubleshoot problems as they arise

214-16 evaluate a personally designed and constructed device on the basis of criteria they have developed themselves

Communication and Teamwork

215-2 select and use appropriate numeric, symbolic, graphical, and linguistic modes of representation to communicate ideas, plans, and results

213-5 compile and organize data, using data tables and graphs, to facilitate interpretation of the data

Knowledge

Students will be expected to

ACP-1 use vector analysis in two dimensions for systems involving two or more masses, relative motions, static equilibrium, and static torques

325-6 analyse quantitatively the horizontal and vertical motion of a projectile

325-8 apply Newton's laws of motion to explain inertia, the relationship among force, mass, and acceleration and the interaction of forces between two objects

325-12 describe uniform circular motion, using algebraic and vector analysis

325-13 explain quantitatively circular motion, using Newton's laws

Projectiles

Outcomes

Students will be expected to

- analyze qualitatively and quantitatively the horizontal and vertical motion of a projectile (325-6)
  - define projectile motion
  - solve problems finding:
    - (i) $\vec{v}_x$ and $\vec{v}_y$ at any point along the path
    - (ii) the range
    - (iii) the maximum height
    - (iv) the final and/or initial velocity (magnitude and direction)
    - (v) flight time
  - sketch the x and y displacement, velocity and acceleration vectors components at any point in the projectile

Elaborations—Strategies for Learning and Teaching

Vector treatment in 2-D (including kinematics equations) should have been covered in Physics 2204. It may be appropiate for the teacher to briefly review this topic.

Teachers should note that projectiles follow a parabolic path. Projectile motion will be limited to negligible air friction, uniform motion in x-direction, and uniform acceleration in the y-direction. Distance in the x-direction is defined as the range and time is a constant in both the x and y direction. The separation of motion into independent *x* and *y* components should be emphasized to students.

The teacher might also want to collaborate with the math teacher to compare projectile motion equations with the equation for quadratic functions.

Programmable/graphic calculators would also be useful in this study, as would a computer simulation program such as Interactive Physics.

Students should be able to solve questions where an object is:

1. moving horizontally and goes over a cliff;
2. projected at an angle and lands at a point above, at or below the point of projection.

Students will not be expected to find the launch angle (other than zero) of a projectile. They should be exposed to the use of the quadratic formula to solve these problems.

Students could undertake an exploratory activity with simple equipment. They could be given the challenge of building a device that would launch marbles from the edge of a table to land in a cup placed at various positions on the floor. They could use materials such as a grooved ruler, a piece of cove moulding, or a curtain track as a launcher. They could then conduct trials to calibrate the launcher for distance from the table. When they are confident they can predict the outcome, the teacher could place a paper cup randomly on the floor to test their accuracy. Students should be monitored to see if they control release position on the launcher and repeat trials when calibrating.

Projectiles

Suggested Assessment Strategies

Paper and Pencil

- An archer shoots an arrow at 1.2×10^2 m/s at a 60.0° angle from the horizontal. Determine the initial horizontal and vertical components of the velocity. (325-6)
- A written lab report should be presented on the investigation of projectile motion. (325-6)
- A projectile is launched at a muzzle velocity of 20.0 m/s at an angle of 57° from the horizontal. Determine the position, horizontally and vertically, from the launch point at 1.5 s. Determine the instantaneous velocity at 1.5 s. At what later time would the *speed* be the same? (325-6)
- A daredevil stunt driver is planning a scene for a movie. She must drive a car horizontally off the roof of a tall building and crash into a window 8.0 m lower in the next building, which is a horizontal distance of 15 m away. Can you help her determine what speed she must have as she reaches the edge of the higher roof? (325-6)
- A skateboarder, coasting with a constant velocity, jumps straight up. When she lands, does she come down: (i) behind the skateboard; (ii) ahead of the skateboard; or; (iii) on the skateboard? Explain your answer. (325-6)
- Explain why projectiles (for which air resistance is negligible) have a maximum range at launch angle of 45^o? (325-6)

Journal

- Students should keep a journal throughout this course. This is a place to write personal reflections. This is also a good place to record things you need to clarify so that you can look back at a later date and ensure your problem is resolved. The journal should include a new entry at least every week. Your first entry could be to distinguish between the changing forces acting on an object in projectile motion. (325-8)

Performance

- Students could experiment with a running garden hose to determine launch angles for hitting targets at various distances. Experimental distances can be verified using projectile motion equations. Students could also determine a percent discrepancy between calculated and experimental values. (325-6)

Resources/Notes

Concepts and Connections

page 84

pages 86 - 93

pages 86 - 93

Projectiles *(continued)*

Outcomes

Students will be expected to

- construct, test and evaluate a device or system on the basis of developed criteria (214-14, 214-16)
- identify questions to investigate that arise from practical problems and issues (212-1)
- compile and organize data, using data tables and graphs, to facilitate interpretation of the data (213-5)
- define and delimit problems to facilitate investigation (212-2)
- use instruments effectively and accurately for collecting data (213-3)
- analyze natural and technological systems to interpret and explain their structure. (116-7)
- distinguish between problems that can be solved by the application of physics-related technologies and those that cannot. (118-8)
- compile and display evidence and information in a variety of formats (214-3)
- analyze and describe examples where technological solutions were developed based on scientific understanding. (116-4)
- define and delimit problems, estimate quantities, and interpret patterns and trends in data, and infer or calculate the relationship among variables. (212-2, 213-4, 214-5)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes 214-14, 214-16, 212-1, 213-5, 212-2, 213-3 and, in part, 325-6 are addressed by completing *Initial Velocity of a Projectile,* CORE LAB #1

The CORE STSE component of this unit incorporates a broad range of Physics 3204 outcomes. More specifically it targets (in whole or in part) 325-6, 116-7, 118-8, 214-3, 116-4,212-2, 213-4, and 214-5. The STSE component, *The Physics of Juggling,* can be found in Appendix B.

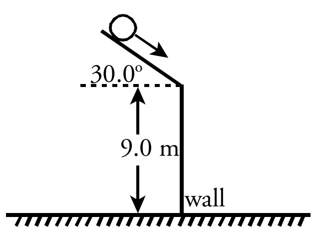
Note that there are additional projectile motion activities at the end of the STSE unit that could be completed to enhance this topic.

Projectiles *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- A trained dog can jump forward at an angle of 37° to the horizontal and with a speed of 3.5 m/s. Where should the trainer hold a hoop so the dog passes through it at his highest point (how far horizontally from the dog's initial position, and how high)? What would be different if the dog jumped from one platform to another each 2.0 m high? (325-6)
- A human cannonball is setting up his act in a new big top. The highest point of the roof of the tent is 12 m from the ground. His "cannon" launches him at an angle of 45° from horizontal. What is the maximum muzzle velocity he can have so as not to punch a hole in the tent roof? (325-6)
- An object is thrown into the air with a velocity of 15 m/s at an angle of 35^0 to the horizontal. How far will this object travel horizontally? (325-6)
- A ball rolls off an incline, as shown, at a velocity of 20.0 m/s. How far horizontally from the wall will the ball hit the surface? (325-6)



Journal

- Conduct research into Canada's participation in the design of artificial satellites such as communication, remote-sensing, and weather observation. Write a journal entry which presents a specific contribution. Do you think Canada bplayed a leadership role in developing this technology? (115-1, 116-4, 117-2)

Resources/Notes

Core Lab #1: *"Initial Velocity of a Projectile* ", **Core Lab: 3.1, page 119**

Core STSE #1: *"The Physics of Juggling"*, Appendix B

Newton's Laws

Outcomes

Students will be expected to

- apply Newton's laws of motion in two dimensions (325-8)
  - solve problems where a single object is pushed or pulled at an angle along a horizontal surface with or without friction

Elaborations—Strategies for Learning and Teaching

Students could develop a list of two-dimensional motions that they have experienced. Carnival rides are a rich source of two-dimensional situations. This list should include the following:

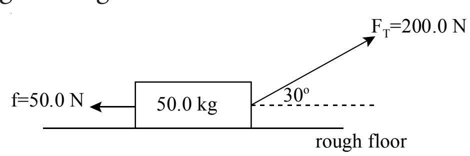
- systems involving two or more masses including horizontal situations, inclined planes, and frictionless pulleys
- static equilibrium applications such as clotheslines and cranes

Students should be able to resolve a vector into its right-angled components, add vectors at right angles, and add multiple vectors using the sum of the components method. Some teachers might elect to do the sine law/cosine law method as an optional mathematical extension.

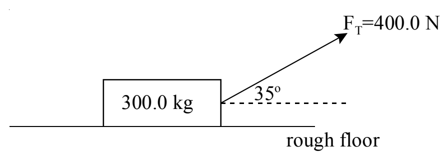
Using Newton's laws of motion, and the concepts of weight and normal force, students should apply free body analysis using thumbnail sketches in all cases.

Teachers should review force vector components, the normal force, and the force of gravity, as well as free body diagrams. Note that in static equilibrium problems, free body diagrams are drawn from a point source (as opposed to torque free body diagrams for rigid bodies).

Teachers should review basic problems like finding the acceleration of the object in the given diagram:



These types of problems are very similar to those completed in Physics 2204. However, now give the students the coefficient of kinetic friction rather than the force of friction. For example, a worker drags a 300.0 kg crate across a factory floor by pulling on a rope tied to the crate as shown in the diagram below. The worker exerts a force of 400.0 N on the rope which is inclined at 35^0 to the horizontal and the coefficient of kinetic friction is 0.10. Determine the acceleration of the crate.



Because the object maybe pushed or pulled, the normal force will now change and, therefore, so will the force of friction because $f_k = \mu_k F_N$.

Note: In the textbook on p. 139 Fig. 4.20A, the solution shown is only correct if one assumes that the lines pulling the sled are parallel to the ground.

Newton's Laws

Suggested Assessment Strategies

Paper and Pencil

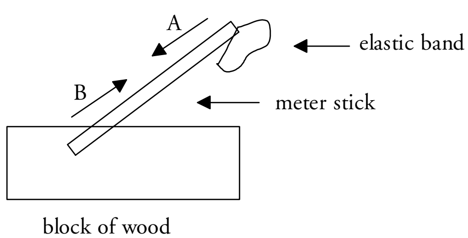
- Three dogs are pulling a sled with ropes that are parallel to the ground. The middle dog pulls with a force of 7.0 x 10^2 N along the centre line of the sled. The dog on the left pulls with a force of 9.0 x 10^2. N at an angle of 20.0° from the centre line, and the other dog pulls with a 6.0 x 10^2 N force at 30.0° from the centre line. What is the net force pulling on the sled? This problem could be done by scaled diagram as well as the sum of components algebraic method. (325-8)
- A 20.0 N object is pulled up an inclined plane. If the inclined plane makes an angle with the horizontal of 37^0, and the coefficient of Kinetic friction is 0.30, what is the force of friction? (325-8)
- An object that has a mass of 48 kg, is pulled along a horizontal surface by a rope that makes an angle of 30.0^0 with the horizontal. The tension in the rope is 90.0 N. If the coefficient of kinetic friction is 0.25, what is the force of friction? (325-8)

Presentation

- Make a short oral presentation providing a free body analysis of your favourite carnival ride. (325-8)

Performance

- Ask students to use the following apparatus to study the effects of pushing or pulling an object with the same force and at a constant angle.



Students should pull the elastic band in direction A as shown. They should note the amount of stretch when the block moves at a constant speed. Then ask them to pull the elastic in direction B until the block moves at a constant speed, and note the amount of stretch. Students should be led through a discussion of the reasons for the differences in amount of stretch in each case. (325-8)

Resources/Notes

Concepts and Connections

pages 137 - 139

Newton's Laws *(continued)*

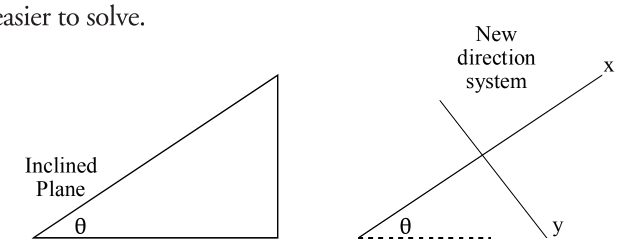
Outcomes

Students will be expected to

- apply Newton's laws of motion in two dimensions (325-8) (**Cont'd**)
  - define an inclined plane and coordinate rotation
  - solve problems for both frictional and non-frictional inclined planes
  - solve problems involving strings and pulleys; on both horizontal surfaces and inclined planes

Elaborations—Strategies for Learning and Teaching

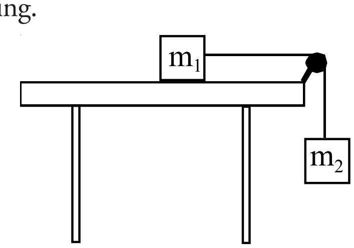
Forces should be defined as perpendicular and parallel components to an inclined plane. Students are use to a direction system where *y* is vertical and *x* is horizontal. It should be pointed out to students that if we use that direction system for an object on an inclined plane it will have to move in both the *x* and *y* direction, and therefore, may be a difficult problem to solve. But, if we rotate our direction system to match the angle of the inclined plane, the object will only be moving in one direction and will be much easier to solve.



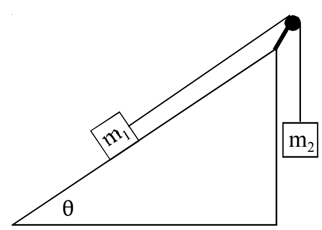
Inclined plane problems should be limited to one incline. The force of friction or the coefficient of friction maybe given in these type of problems.

The horizontal surface problems would be very similar to the problems covered in physics 2204. The new problems will involve the inclined plane and friction. Inclined plane problems should be limited to one incline and one pulley. Students should be exposed to the following possible set-ups and asked to find the acceleration of the blocks and/or the tension in the string.

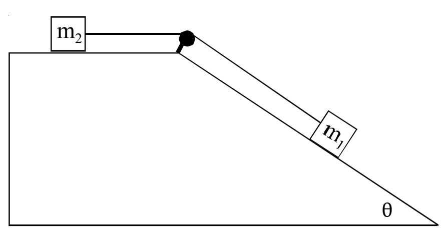
A)



B)



C)



Teachers should note that when solving problems with pulleys and friction on a surface, the direction of motion will be given.

In questions like diagram (c), friction may be present on one or both surfaces.

Newton's Laws *(continued)*

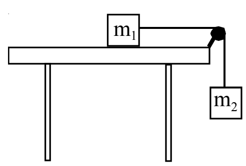
Suggested Assessment Strategies

Journal

- Give some everyday examples of situations where friction is beneficial. (325-8)
- Can an object be in equilibrium if it is moving? Explain. (325-8)
- A friend tells you that since his car is at rest, there are no forces acting on it. How would you reply? (325-8)

Paper and Pencil

- A seal slides from rest down a 3.5 m long ramp into a pool of water. If the ramp is inclined at an angle of 25° above the horizontal and the coefficient of kinetic friction between the seal and the ramp is 0.20, how long does it take for the seal to make a splash in the pool? (325-8)
- A block of mass m_1 slides on a horizontal table. It is connected to a string that passes over a massless, frictionless pulley and suspends a mass m_2. Find the equations for the acceleration of the system and tension in the string in terms of m_1, m_2 and g. (325-8)



- A 10.0 kg object is at rest on an inclined plane. If the inclined plane makes an angle with the horizontal of 35^0, what is the normal force acting on the object? (325-8)

Resources/Notes

Concepts and Connections

page 194

pages 194 - 196

pages 197 - 202

Uniform Circular Motion

Outcomes

Students will be expected to

- describe uniform circular motion using algebraic and vector analysis (325-12)
  - define uniform circular motion (UCM) and centripetal acceleration using the formulae $v = \frac{2\pi r}{T}$ and $a_c = \frac{v^2}{r}$ and when these are used in combination.
  - solve problems involving centripetal acceleration
- explain quantitatively uniform circular motion using Newton's laws (325-13)
  - define centripetal force $\vec{F}_c = \frac{m\vec{v}^2}{r}$

Elaborations—Strategies for Learning and Teaching

Students have considerable experience with circular motion. The playground carousel, bicycle wheels, and the Ferris wheel have all contributed to a practical sense of circular motions.

Students should be able to solve problems using the equations: $v = \frac{2\pi r}{T}$ and $a_c = \frac{v^2}{r}$ and their combinations (also with $T = \frac{1}{f}$). Teachers could derive the formula $ac = \frac{v^2}{r}$, however students will not be resposible for this derivation. The additional derived formulae for circular motion are not on the Public Exam formula sheet, and while useful, do not need to be memorized to do circular motion problems. These formulae include:

$$Ac = \frac{4\pi^2 r}{T^2}$$

$$Ac = 4\pi^2 r f^2$$

$$Fc = \frac{m4\pi^2 r}{T^2}$$

$$Fc = m4\pi^2 r f^2$$

These formulae are useful, however, in the analysis of the results of the core lab for circular motion.

Teachers could ask questions such as, what happens to passengers when a car takes a turn very quickly? (Does the car pull into the passengers, or do they slam into the side of the car?) Students should be asked how quickly these objects are rotating near the axis and away from the axis. How quickly do the hands of a watch rotate? These motions need to include the direction of rotation.

Two students could do a demonstration, with one student standing in one position but free to rotate and the second holding on by one hand and at right angles to the first student. If the outer student tries to move straight ahead and maintains the right-angled orientation, a circular path should result. The result may be more visible if a short cord (about a metre) is used to separate the two students. Other students could be asked to show on the board or overhead the orientation and relationship between centripetal force and velocity.

Uniform Circular Motion

Suggested Assessment Strategies

Journal

- Look around your environment for situations that involve circular motion. Reflect and comment on three examples. (325-13)
- Research centrifugation and production of high apparent weights in centrifuges and their application to medicine and engineering. (325-12, 325-13)

Paper and Pencil

- Prepare a written lab report on the centripetal force experiment/ demonstration. (325-12)
- In a Celtic field event called the hammer throw, a 12 kg ball is whirled in a circle of radius 2.0 m with a frequency of 1.5 Hz. What is the velocity when it is released? What is the centripetal force? (325-13)
- How can a motion with constant speed be an accelerated motion? (325-13)
- Suppose a plane flies in a circular path of circumference 20.0 km at a speed of 200.0 km/h. What is the change in velocity in one quarter of a revolution? What is the change in velocity in half a revolution? (325-13)
- If centripetal acceleration is given by the expression v^2/r, prove that the dimensions are correct for acceleration. (325-13)
- If the speed of an object in circular motion is doubled, what effect will this have on the centripetal force? (325-13)

Resources/Notes

Concepts and Connections

pages 202 - 211

pages 202 - 211

page 207

Uniform Circular Motion *(continued)*

Outcomes

Students will be expected to

- explain quantitatively uniform circular motion using Newton's laws (325-13)

  - solve problems involving centripetal force/acceleration on a horizontal surface and at the top and bottom of a vertical circle

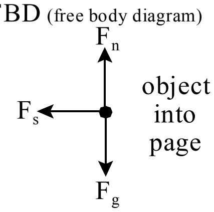
Elaborations—Strategies for Learning and Teaching

Students should move from a discussion of familiar experiences to a more analytical examination. Teachers should point out to students that the following progression in concept development has occurred. First, linear motions were studied in which a force changes only the magnitude of an object's velocity. Second, in the study of projectiles, students learned that a force can change both the magnitude and direction of a velocity. Finally, in the case of circular motion, students saw that a force applied at a right angle to a velocity, changes only the direction of motion. This is a very abstract concept. It is difficult to accept that a force can result in a change in direction only.

Students should now be able to move from $\vec{F}_{net} = m\vec{a}$ to $\vec{F}_c = m\vec{a}_c$ and substitute for $\vec{a}_c$, to get $\vec{F}_c = \frac{m\vec{v}^2}{r}$.

Horizontal surface: It should be pointed out to students that it is the force of static friction (not kinetic friction) that keeps an object in UCM.

FBD (free body diagram)



x-direction

$$\vec{F}_{net} = m\vec{a}$$

and for UCM

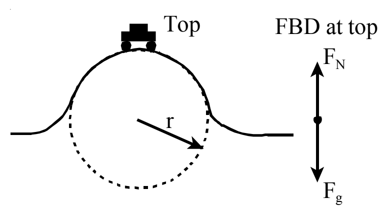
$$\vec{F}_c = m\vec{a}_c$$

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

Students will not be expected to find the coefficient of static friction. Forces for vertical circles will be limited to the normal force, gravitational force and tension.

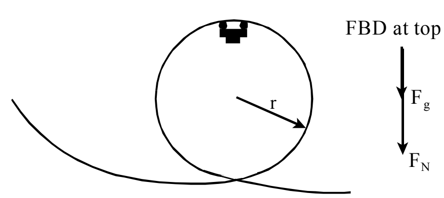
Vertical surface: Students should be exposed to problems such as:

- a car going over a hill top.



- a roller coaster; either inside or outside the track.

Inside (loop-the-loop)



Uniform Circular Motion *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- How fast must a plane fly in a loop-the-loop stunt of radius 2.0 km if the pilot experiences no force from either the seat or the safety harness when he is at the top of the loop? To be considered "weightless," all forces on the pilot must be in balance, or the gravitational force must be entirely used up in providing the centripetal force. (325-13)
- A string used to make a pendulum has a breaking strength of 12.0 N and a length of 0.80 m. A 1.00 kg mass is used as a bob and set in motion.
  - If the bob moves with a speed of 1.00 m/s at the bottom of the swing, will the string break?
  - What is the critical speed (the highest speed at the bottom of the arc so that the string does not break)?
  - What is the maximum release height so that the string does not break? (*Hint: use conservation of energy from Physics 2204.*) (325-3)
- A 1.5 kg object is swung from the end of a 0.62 m string in a vertical circle. If the time of one revolution is 1.2 s, what is the tension in the string? Assume the object is moving at uniform speed. (325-13)

Performance

- Students can also attempt to qualitatively determine the minimum speed required to spin a bucket of water in a vertical circle without spilling the water. (325-12, 325-13)

Resources/Notes

Concepts and Connections

pages 208 - 210

Uniform Circular Motion *(continued)*

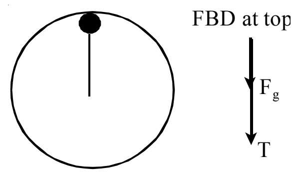
Outcomes

Students will be expected to

- explain quantitatively uniform circular motion using Newton's laws (325-13) (**Cont'd**)

Elaborations—Strategies for Learning and Teaching

- a ball being swung on a massless string.



Students may have difficulty with these type of problems because of the vector nature of the forces and the acceleration. Teachers could solve the direction problem by always letting "towards the centre of the circle" be positive. Therefore:

for the car :

$$\vec{F_c} = m\vec{a_c}$$
$$\vec{F_g} + \vec{F_N} = m\vec{a_c}$$
$$F_g - F_N = \frac{mv^2}{r}$$

AND

for the roller coaster:

$$\vec{F_c} = m\vec{a_c}$$
$$\vec{F_g} + \vec{F_N} = m\vec{a_c}$$
$$F_g + F_N = \frac{mv^2}{r}$$

AND

for the ball:

$$\vec{F_c} = m\vec{a_c}$$
$$\vec{F_g} + \vec{T} = m\vec{a_c}$$
$$F_g + T = \frac{mv^2}{r}$$

Once the equations are set up, the students can solve for any one missing variable.

- solve problems for banked curves without friction

Students would not be expected to develop the formula: $r = \frac{v^2}{g\tan\theta}$

since it may cause some difficulty with the earlier work on inclined planes. Therefore, the teacher could present it (with or without derivation) to the students. It should be noted that $v = \sqrt{rg\tan\theta}$ is a useful rearrangement of this formula.

An effective approach to UCM would be to start with a horizontal surface, move to a banked surface and then to vertical circles.

Uniform Circular Motion *(continued)*

Suggested Assessment Strategies

Paper and Pencil

- Due to the rotation of Earth, an object has less apparent weight at the equator than at the North Pole. (Some of the gravitational force is used to maintain the circular path on the surface of Earth.)
  - What does a 100.0 kg person weigh at the north pole?
  - What does the same person weigh at the equator? (325-13)
- A car goes around a curve on a road that is banked at an angle of 30.0°. Even though the road is slick, the car will stay on the road. without any friction between its tires and the road, when its speed is 22m/s. What is the radius of the curve? (325-13)
- Calculate the angle at which a frictionless curve must be banked if a car is to round it safely at a speed of 75 km/h. The radius of the curve is 5.0×10^2 m. (325-13)

Journal

- Research applications of banked curves such as,
  - race tracks
  - skateboard parks
  - velodromes
  - roulette tables
  - baggage handlers at airports. (325-13)

Resources/Notes

Concepts and Connections

pages 210 - 211

Uniform Circular Motion *(continued)*

Outcomes

Students will be expected to

- define and delimit problems to facilitate investigation (212-2)
- compile and display evidence and information in a variety of formats, including tables, graphs, and scatter plots (214-3)
- interpret patterns and trends in data, and infer or calculate linear and non-linear relationships among variables (214-5)
- use instruments effectively and accurately for collecting data (213-3)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes 212-2, 214-3, 214-5, 213-3 and, in part, 325-13 are addressed by completing *Centripetal Force and Centripetal Acceleration,* CORE LAB #2. It is suggested that teachers do not use a long string for safety reasons. Teachers may also wish to mark the string where the paper clip is located because the clip may move.

The traditional centripetal force experiment involving weights being swung in circular motion while held in place by a suspended mass can be done at this point. It is recommended that students swing a rubber stopper instead of a weight. Through discussion, students could suggest ways to control variables during trials. The relationship of frequency to velocity should be developed.

Uniform Circular Motion *(continued)*

Suggested Assessment Strategies

Journal

- Two forces produce the same torque. Do they have the same magnitude? Explain. (ACP-1)
- A tightrope-walker uses a long pole to aid in balancing. Why? (ACP-1)
- Give an example of a system in which the net torque is zero but the net force is non-zero. (ACP-1)
- Give some examples of everyday objects that are in static equilibrium and not in static equilibrium. (ACP-1)

Performance

- Design and construct a mobile, noting mass and length of arms for all sections, using your knowledge of static equilibrium. (ACP-1)

Resources/Notes

Core Lab #2: *"Centripetal Force and Centripetal Acceleration"*, **page 228**

Static Equilibrium and Torque

Outcomes

Students will be expected to

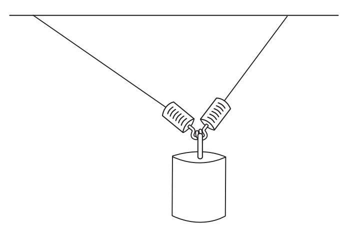
- use vector analysis in two dimensions for systems involving two or more masses, static equilibrium, and torques (ACP-1)
  - define
    - (i) translational euilibrium $\left(\vec{F}_{net} = 0\right)$
    - (ii) rotational equilibrium $\left(\vec{T}_{net} = 0\right)$
    - (iii) static equilibrium $\left(\vec{F}_{net} = 0, \vec{T}_{net} = 0\right)$
  - define center of mass
  - solve translational equilibrium force problems
- interpret patterns and trends in data, and calculate relationships among variables (214-5)
- define and delimit problems to facilitate investigation (212-2)
- use instruments effectively and accurately for collecting data (213-3)
- evaluate a personally constructed device on the basis of criteria they have developed themselves (214-16)

Elaborations—Strategies for Learning and Teaching

The first condition for static equilibrium ($F_{net} = 0$) is simply an applicaiton of Newton's second law studied previously. Teachers should remind students that translational equilibrium problems have already been done in the Newton's 2nd law section. In order for an object to experience static equilibrium both the net force **AND** net torque must be zero.

Students need to be aware that forces acting on stationary objects are not always easy to deal with. Forces often act at many angles besides 90 degrees, which adds an extra dimension to problem-solving. Examples may include hanging a picture, traffic lights, pulling objects up/down a hill at constant velocity or loading a truck's cargo so that it doesn't move when the truck climbs a hill. Also, examples should include forces causing rotational motion (torques).

A hanging mass apparatus could be constructed using two spring scales supporting an unknown mass. Each spring scale should be attached by a string (unequal lengths) to a horizontal support rod. By measuring appropriate angles and performing vector calculation, the unknown mass can be determined.



Students are not expected to calculate center of mass, but to know where it is for a uniform body.

Teachers should place a strong emphasis on drawing good free body diagrams.

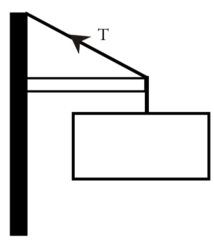
The Laboratory outcomes 214-5, 212-2, 213-3, 214-16 and in part, ACP-1 are addressed by completing *Equilibrium in Forces,* CORE LAB #3

Static Equilibrium and Torque

Suggested Assessment Strategies

Paper and Pencil

- Pat and Ahmed are playing on a 4.0 m long seesaw that is supported at the centre. If Pat has a mass of 30.0 kg and sits at one end of the seesaw, where should Ahmed (mass = 35 kg) sit so that the seesaw balances? (ACP-1)
- A 1.5×10^3 kg car is crossing a 1.2×10^2 m long flat bridge which is supported at both ends. When the car is 32 m from one end, what force must each end support be able to provide? (ACP-1)
- Determine the tension in the cable and the compression force in the boom to support the 1.0×10^2 kg boom. The angle between the boom and the supporting cable is 37° C. (ACP-1)



- A playground seesaw with a total length of 5.0 m and a mass of 30.0 kg is pivoted at its center. A 20.0 kg child sits on one end of the seesaw.
  - a) Where should a person push with a force of 2.2×10^2 N in order to hold the seesaw level?
  - b) Where should a 40.0 kg child sit to balance the seesaw? (ACP-1)

Resources/Notes

Concepts and Connections

page 232

page 233

page 243

pages 234 - 237

Core Lab #3: *"Equilibrium in Forces"*, **page 272**

Static Equilibrium and Torque *(continued)*

Outcomes

Students will be expected to

- use vector analysis in two dimensions for systems involving two or more masses, static equilibrium, and torques (ACP-1) (**cont'd**)
  - define torque (moment of force)
  - calculate torque when forces are applied either perpendicularly or at an angle
  - solve static equilibrium problems: balancing forces and torques

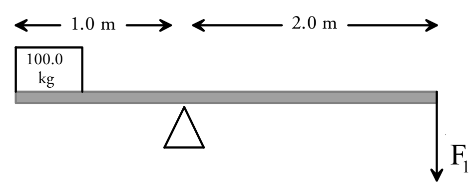
Elaborations—Strategies for Learning and Teaching

Problems can be solved by resolving the force perpendicular to the rigid arm with which the force is in contact. The students can use *sin* or *cos* to find the perpendicular force component. The direction system can be simplified by letting the sum of the clockwise torques equal the sum of the counter clockwise torques, i.e., $\tau_{CW} = \tau_{CCW}$ which is the same as $\tau_{net} = 0$.

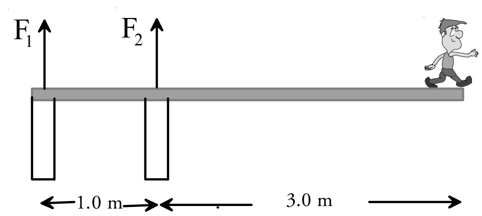
Teachers should note that solving static equilibrium problems is simplified by using $\tau_{CW} = \tau_{CCW}$ as opposed to $\tau_{net} = 0$ as done in the texbook. Some common torque problems that should be addressed are:

- Seesaw problems

  Example: What force F_1 is needed to balance the 100.0 kg mass shown?

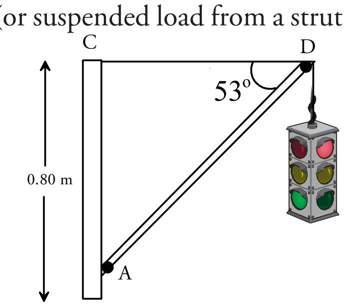


- cantilever problems (e.g., diving board)



  Example: Calculate the forces F_1 and F_2 that the supports exert on the uniform diving board shown when a 50.0 kg person stands at its tip. The mass of the board is 40.0 kg.

- crane problems (or suspended load from a strut and cable).



  Example : A traffic light hangs from a structure as shown. The uniform aluminum pole AD is 4.0 m long and weighs 5.0 kg. The weight of the traffic light is 10.0 kg. Determine the tension in the horizontal, massless cable CD. Determine the vertical and horizontal components of the force exerted by the pivot A on the aluminum pole.

Static Equilibrium and Torque *(continued)*

Suggested Assessment Strategies

Resources/Notes

Concepts and Connections

page 238

Static Equilibrium and Torque *(continued)*

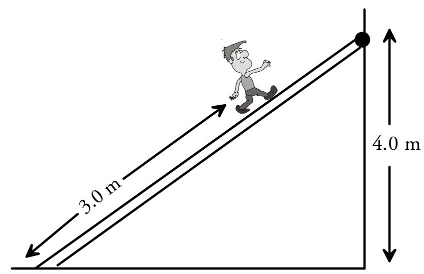
Outcomes

Students will be expected to

- use vector analysis in two dimensions for systems involving two or more masses, static equilibrium, and torques (ACP-1) (**cont'd**)

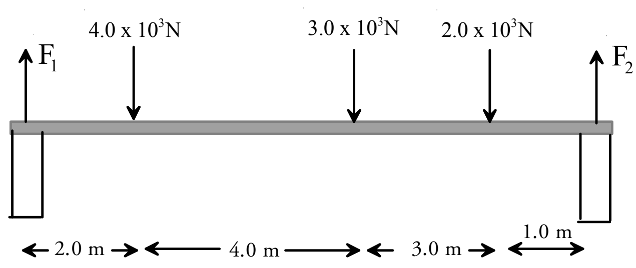
Elaborations—Strategies for Learning and Teaching

- ladder problems



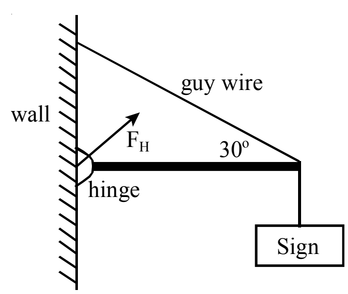
Example: A 5.0 m long ladder leans against a wall at a point 4.0 m above the ground as shown. The ladder is uniform and has a mass of 12.0 kg. A 55 kg painter is standing 3.0 m up the ladder. Assuming the wall is frictionless (but the ground is not) determine the forces exerted on the ladder by the ground and the wall.

- horizontal bridge or beam problems



Example: Calculate F_1 and F_2 for the beam shown. Assume the beam is uniform and has a mass of 280.0 kg.

For example; a uniform rod of length L and mass of 4.0 Kg is hinged at the left end. A 25.0 Kg sign is suspended from the right end. A guy wire is connected to the end of the rod and fastened to a wall. Determine the tension in the guy wire.



Static Equilibrium and Torque *(continued)*

Suggested Assessment Strategies

Resources/Notes

pages 239 - 240

pages 243 - 251

Static Equilibrium and Torque (*continued*)

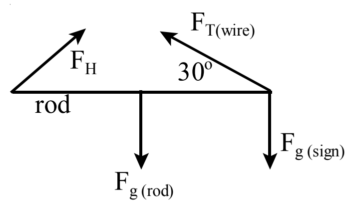
Outcomes

Students will be expected to

- use vector analysis in two dimensions for systems involving two or more masses, static equilibrium, and torques (ACP-1) (**cont'd**)

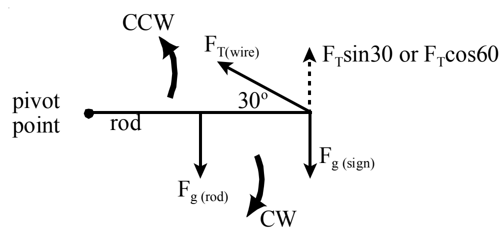
Elaborations—Strategies for Learning and Teaching

A good strategy to solve this type of problem is for the students to first start with a FBD of all forces acting on the rod.



Free Body Diagram

If they then choose the left end as the pivot point, the force of the hinge can be removed from the problem (distance equals zero, therefore, torque equals zero). The problem can now be simplified to:



Note that free body diagrams for rigid arms are different from free body diagrams from a point source, in that they illustrate forces acting at any point on the rigid arm.

For problems involving a ladder (or other object) leaning against a wall, the wall should be considered frictionless. These problems should be limited to three forces acting in different directions (i.e., three different sets of components).

Static Equilibrium and Torque *(continued)*

Suggested Assessment Strategies

Resources/Notes