TOPIC 4.1: GRAVITATIONAL FIELDS

Students define the gravitational force constant g as a force per unit mass in N/kg, and the weight as $F_g = mg$. The acceleration due to gravity (i.e., $a_g = g$) is derived from Newton's laws and determined in the laboratory. Students describe the normal force in terms of the mutual attraction of masses, and draw simple free-body diagrams.

The student will be able to:

S3P-4-01: Define the gravitational field qualitatively as the region of space around a mass where another point mass experiences a force.

S3P-4-02: Diagram the Earth's gravitational field, using lines of force.

S3P-4-03: Define the gravitational field quantitatively as a force per unit mass.

S3P-4-04: Compare and contrast the terms "mass" and "weight."

S3P-4-05: Describe, qualitatively and quantitatively, apparent weight changes in vertically accelerating systems.
Examples: elevators, spacecraft…

S3P-4-06: Derive the acceleration due to gravity from free fall and Newton's laws.

S3P-4-07: Perform an experiment to calculate g near the surface of the Earth.

S3P-4-08: Solve free-fall problems.

S3P-4-09: Describe terminal velocity, qualitatively and quantitatively.

S3P-4-10: Define the coefficient of friction (μ) as the ratio of the force of friction and the normal force.

S3P-4-11: Distinguish between static and kinetic friction.

S3P-4-12: Compare the effects of the normal force, materials involved, surface area, and speed on the force of friction.

S3P-4-13: Solve problems with the coefficient of friction for objects on a horizontal surface.

General Learning Outcome Connection

Students will...

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

Specific Learning Outcomes

S3P-4-01: Define the gravitational field qualitatively as the region of space around a mass where another point mass experiences a force.

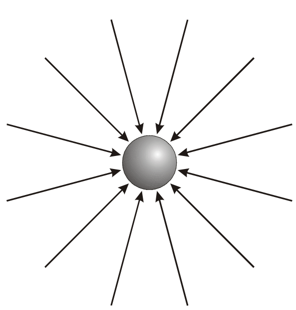
S3P-4-02: Diagram the Earth's gravitational field using lines of force.

Suggestions for Instruction

Notes to the Teacher

Discuss with students the universal nature of the attraction between any two masses. Extend the discussion to the case of the Earth's gravitational field. Michael Faraday introduced the concept of "field lines" to represent the strength and direction of the force. More field lines per unit area represent a stronger field. This occurs in regions where the lines are closer together. The direction of the field is the direction the force would act on a "test mass" brought into the field. A "test mass" simply means "as if we put a mass of 1 kg in the field."

Note: The gravitational field is continuous and the field lines just provide a visual representation of the field.



The diagram indicates that the field lines get further apart as the gravitational field strength gets weaker.

Teacher Demonstration

Demonstrate the field of the Earth with a mass and spring scale (calibrated in newtons).

Senior Years Science Teachers' Handbook Activities

Students use a Concept Frame and Concept Overview (see *Senior Years Science Teachers' Handbook*, Attachments 11.2 and 11.3) to develop the concepts of the gravitational field and its associated field lines.

Use a Listen-Draw-Pair-Share sheet for an introduction to the gravitational field concept (see *Success for All Learners: A Handbook on Differentiating Instruction*, Attachment 5, and *Senior Years Science Teachers' Handbook*, Building a Scientific Vocabulary, Developing Scientific Concepts Using Graphic Displays, Attachments 10.2, 11.2, and 11.3).

SKILLS AND ATTITUDES OUTCOMES

S3P-0-1c: Relate the historical development of scientific ideas and technology to the form and function of scientific knowledge today.

S3P-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...

Understand the composition of the Earth's atmosphere, hydrosphere, and lithosphere, as well as the processes involved within and among them (GLO D5)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Visual Display

Students explain, with the aid of diagrams, the gravitational field of the Earth.

Self-Assessment

Use a vocabulary strategy with students (e.g., Three-Point Approach) to demonstrate their qualitative and quantitative understanding of the term "gravitational field." (See *Senior Years Science Teachers' Handbook*, Building a Scientific Vocabulary, page 10.1.)

SUGGESTED LEARNING RESOURCES

Appendix 4.2: Journal Entry: Gravitational Fields

GENERAL LEARNING OUTCOME CONNECTION

Students will...

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

SPECIFIC LEARNING OUTCOMES

S3P-4-03: Define gravitational field quantitatively as a force per unit mass.

S3P-4-04: Compare and contrast the terms "mass" and "weight."

SKILLS AND ATTITUDES OUTCOMES

S3P-0-1c: Formulate operational definitions of major variables or concepts.

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

The gravitational field strength is defined as the gravitational force that a "test mass" would experience at some point in the field. That is, $g = \frac{F_g}{m}$. The units of **g** are $\frac{N}{\text{kg}}$.

Near the surface of the Earth, **g** is 9.8 N/kg directed towards the centre of the Earth. Students should understand that every kilogram of mass near the Earth experiences 9.8 newtons of force. Students should also recognize that to define **g** operationally, we can measure force, using a spring scale, and mass, using a balance.

Student Activities

Students solve for various problem situations, using F_g = mg. See Appendix 4.1: Vertical Motion at the Earth's Surface.

Teacher Demonstration

Discuss or demonstrate (by changing the faceplate of a spring scale) what a spring scale would read on the surface of various celestial bodies (Moon, planets, Sun, et cetera).

Senior Years Science Teachers' Handbook Activities

Students use a vocabulary strategy (e.g., Three-Point Approach) to demonstrate their quantitative understanding of the term "gravitational field." (See *Senior Years Science Teachers' Handbook*, Building a Scientific Vocabulary.)

Students compare and contrast mass and weight, using the *Senior Years Science Teachers' Handbook* Compare and Contrast Frame.

Students research the **g** value for various locations (e.g., Winnipeg), using the Internet (National Research Council). Provide examples of different values of **g** on Earth (equator versus poles; Winnipeg versus Mount Everest) and different values of **g** for celestial bodies (planets/moons, stars).

Interpretation of Media Reports

Discuss the effects on the human body when exposed to lower/higher **g** environments for an extended period of time (e.g., International Space Station astronauts).

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2f: Record, organize, and display data, using an appropriate format.

Include: labelled diagrams, tables, graphs

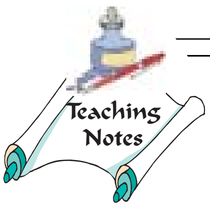
S3P-0-3b: Describe examples of how technology has evolved in response to scientific advances, and how scientific knowledge has evolved as the result of new innovations in technology.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

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



SUGGESTIONS FOR ASSESSMENT

Students prepare a lab report using Laboratory Report Outline, Attachment 11.4, *Senior Years Science Teachers' Handbook.*

Students use a Concept Frame and Concept Overview, Attachments 11.2 and 11.3, *Senior Years Science Teachers' Handbook.*

Students solve problems for any variable in $F_g = mg$, given the other two. Assume that frictional effects are negligible.

SUGGESTED LEARNING RESOURCES

References

Iona, M. (April 1999) "Weight—An Official Definition." *The Physics Teacher* 37:4: 238.

Senior Years Science Teachers' Handbook, Writing to Learn Science, Technical Writing in Science, and Building a Scientific Vocabulary (Manitoba Education and Training, 1997)

Appendix 4.1: Vertical Motion at the Earth's Surface

Appendix 4.2: Journal Entry: Gravitational Fields

GENERAL LEARNING OUTCOME CONNECTION

Students will…

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

SPECIFIC LEARNING OUTCOME

S3P-4-05: Describe, qualitatively and quantitatively, apparent weight changes in vertically accelerating systems.

Examples: elevators, spacecraft…

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

Draw free-body diagrams of an object in a moving system (elevator) under different conditions (i.e., constant velocity, acceleration upward, or acceleration downward).

Solve problems for apparent weight in a moving system (elevator) under different conditions (i.e., constant velocity, acceleration upward, or acceleration downward).

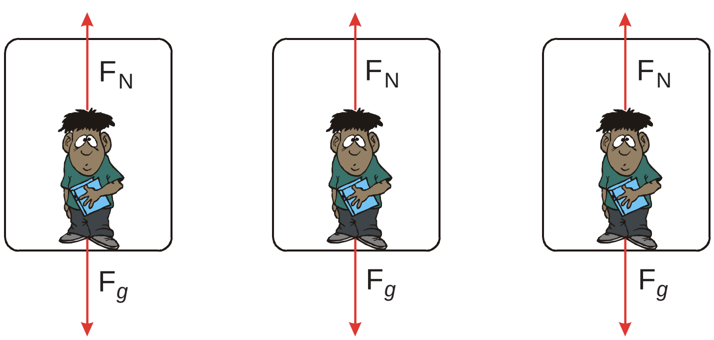


Diagram A
constant velocity
($a = 0$ m/s^2)
$F_{net} = ma$
$F_N + F_g = 0$
$F_N = -F_g$
$|F_N| = |F_g|$

Diagram B
accelerated motion upward
($a > 0$)
$F_{net} = ma$
$F_N + F_g = (+)$
$F_N = (+) + (-F_g)$
$= (+) + (+)$
$\therefore |F_N| > |F_g|$

Note that this applies to elevator accelerating while going up or slowing while going down.

Diagram C
accelerated motion downward
($a < 0$)
$F_{net} = ma$
$F_N + F_g = (-)$
$F_N = (-) + (-F_g)$
$= (-) + (+)$
$\therefore |F_N| < |F_g|$

Note that this applies to elevator slowing while going up or accelerating while going down.

$F_{net} = F_g + F_N$, where F_N is the apparent weight of the object, sometimes referred to as F_{SCALE}.

Student Activities

Students videotape apparent weight changes in an accelerating elevator or examine various amusement park physics demonstrations involving vertical accelerations (e.g., rollercoaster).

Senior Years Science Teachers' Handbook Activities

Students research and report on various micro-gravity environments and their effects on the human body.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

S3P-0-2b: Propose problems, state hypotheses, and plan, implement, adapt, or extend procedures to carry out an investigation where required.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Describe and appreciate how the natural and constructed world is made up of systems and how interactions take place within and among these systems (GLO E2)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Visual Displays

Students explore directly (by visiting), or through a simulation, the physics of an amusement park ride. Complete a poster, diagram, or model that outlines forces relationships, and apparent weight changes.

Answering Questions Based on Data

Students calculate apparent weight under different conditions.

SUGGESTED LEARNING RESOURCES

Jensen, L. (1986) "Apparent Weight Changes in an Elevator." *A Potpourri of Physics Teaching Ideas*: 89.

Evans, L. and J. Stevens. (1978) "Which Way Is Up?" *The Physics Teacher* 16:8: 561.

Multimedia

Physics at Work: Side A/B, Frames 491, acceleration; 494, skydivers; 511, free fall; 393-94, 605, 613-17, 639-40, 648-51.

Physics of Flight: Frames 37277..., Viscous Flow; 27115..., 30642..., Aerodynamic Lift; 41399..., Motion of free-fall parachutist; 1155-59

Interactive Physics Simulations

General Learning Outcome Connection

Students will...

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

Specific Learning Outcomes

S3P-4-06: Derive the acceleration due to gravity from free fall and Newton's laws.

S3P-4-07: Perform an experiment to calculate *g* near the surface of the Earth.

Skills and Attitudes Outcomes

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

Suggestions for Instruction

Notes to the Teacher

Show the derivation for acceleration due to gravity:

For free fall:

$F_{net} = ma$ where

$F_{net} = F_{applied} + F_{friction}$

$F_{applied} = F_g$ and $F_{friction} = 0$
(assuming no air resistance)

$F_{net} = F_g$

$ma = mg$

$a = g$

There are several ways to calculate **g** experimentally. Examples of these include:

- Perform a tickertape experiment, using a free-falling mass, and plot d-t, v-t, and a-t graphs.
- Conduct microcomputer-based experiments to determine **g**:
- Use spring scales (calibrated in newtons) and masses to determine **g** by plotting the gravitational force (spring scale reading) versus mass on a graph. The slope of the graph determines the value of **g**.

Student Activities

Students solve problems, using kinematic equations from learning outcome S3P-1-07 and $F_g = mg$.

Students interpret free-fall motion from videos, using graphs produced with *Videograph* software.

Students perform free-fall simulations, using *Interactive Physics Simulations* software.

Multimedia Simulations

Software: *Interactive Physics Simulations*, Activities #3: Free Fall; #6: Grape Drop

Physics with Computers (Vernier)—Experiment #5: Picket Fence Free Fall

Physics with Computers (Vernier)—Experiment #6: Ball Toss

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2d: Estimate and measure accurately, using Système International (SI) units.

S3P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data-collection methods.

Include: discrepancies in data and sources of error

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Understand the composition of the universe, the interactions within it, and the impacts of humankind's continued attempts to understand and explore it (GLO D6)

SUGGESTIONS FOR INSTRUCTION

Teaching Notes

SUGGESTIONS FOR ASSESSMENT

Students solve free-fall problems limited to vertical motion only using kinematic equations and F_g = mg. See Appendix 4.1: Vertical Motion at the Earth's Surface.

SUGGESTED LEARNING RESOURCES

Journals

Court, J. (1993) "Free Body Diagrams." *The Physics Teacher* 31:2: 104.

Court, J. (1999) "Free Body Diagrams." *The Physics Teacher* 37:7: 427.

Fisher, K. (1999) "Exercise in Drawing and Utilizing Free-Body Diagrams." *The Physics Teacher* 37.7: 434.

Evans, L. and J. Stevens. (1978) "Which Way Is Up?" *The Physics Teacher* 16.8: 561.

Software

Interactive Physics Simulations, Activities #3: Free Fall; #6: Grape Drop

Physics with Computers (Vernier)—Experiment #4: Determining **g** on an Incline.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

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

SPECIFIC LEARNING OUTCOME

S3P-4-08: Solve free-fall problems.

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2a: Select and use appropriate visual, numeric, graphical, and symbolic modes of representation to identify and represent relationships.

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

In free fall, air resistance varies with the square of the speed (generally, $F_{air} \propto v^2$). Therefore, as speed increases, air resistance also increases. In terms of the force vectors, the progression from a free-falling object as it achieves terminal velocity can be diagrammed as follows:

Students solve free-fall problems using the kinematics relations from outcome S3P-3-07. It should be noted that even though the motion is accelerated and the velocity changes, the average velocity is still a useful concept in solving these types of problems. It is also useful for students to sketch and compare graphical solutions to the algebraic relationships.

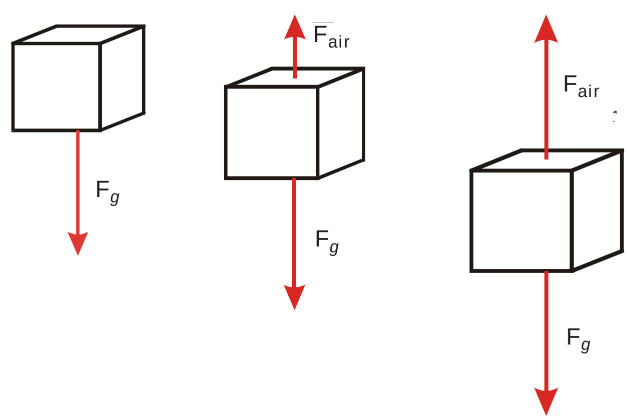


Diagram a
Free fall begins (no air resistance)
$F_{net} = F_g$
$a = g$

Diagram b
Object falling in air, resistance increases
$F_{net} = F_g + F_{air}$
$a =< g$

Diagram c
As velocity increases, air resistance increases until $F_{air} = -F_g$
$F_{net} = 0$ and $a = 0$
Velocity is constant (terminal velocity)

SKILLS AND ATTITUDES OUTCOMES

S3P-0-2d: Estimate and measure accurately, using Système International (SI) units.

S3P-0-2e: Evaluate the relevance, reliability, and adequacy of data and data-collection methods.

Include: discrepancies in data and sources of error

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life (GLO C8)

SUGGESTIONS FOR INSTRUCTION

Teacher Demonstration

Demonstrate and describe terminal velocity (e.g., compare dropping flat paper versus crumpled paper).

Student Activities

Students interpret free-fall motion from videos, using graphs produced with software.

Students perform free-fall simulations using *Interactive Physics Simulation* software.

SUGGESTIONS FOR ASSESSMENT

Students solve free-fall problems limited to vertical motion only, using kinematic equations and F_g = mg.

Students compare free-falling objects and terminal velocity of objects, using a Compare and Contrast Frame from page 10.24 of the *Senior Years Science Teachers' Handbook*.

SUGGESTED LEARNING RESOURCES

Software

Interactive Physics, Activities #3: Free Fall; #6: Grape Drop

Multimedia

Videodiscs: *Physics at Work*: penny and feather

Video Encyclopedia of Physics Demonstrations: penny and feather

Physics of Flight: Motion of free-fall parachutist

GENERAL LEARNING OUTCOME CONNECTION

Students will…

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

SPECIFIC LEARNING OUTCOMES

S3P-4-09: Describe terminal velocity, qualitatively and quantitatively.

S3P-4-10: Define the coefficient of friction (μ) as the ratio of the force of friction and the normal force.

S3P-4-11: Distinguish between static and kinetic friction.

S3P-4-12: Compare the effects of the normal force, materials involved, surface area, and speed on the force of friction.

S3P-4-13: Solve problems with the coefficient of friction for objects on a horizontal surface.

SUGGESTIONS FOR INSTRUCTION

Notes to the Teacher

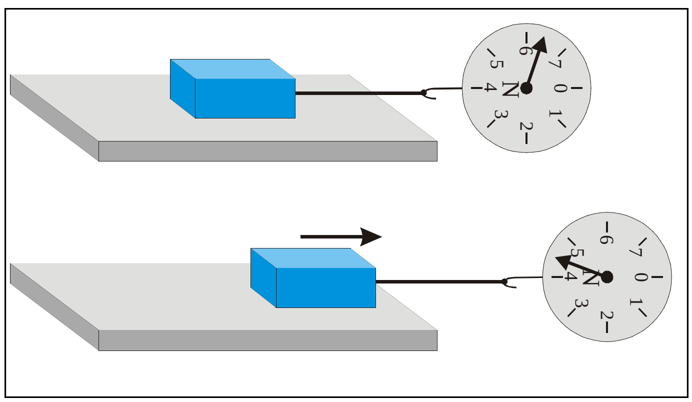
For a given pair of surfaces, the force of friction generally acts opposite to the direction of relative motion or attempted motion between the two surfaces. Note that a common misconception is that friction always acts to oppose motion (i.e., to make things stop moving). While friction usually does act to make things stop, it is also capable of making things move and speed up. An example of this would be a box sitting on a flatbed truck. If both were at rest when the truck gently accelerated forward, the inertial tendency of the box would be to remain at rest. An accelerating truck and a stationary box would produce rubbing between the two surfaces. Friction opposes this relative motion, causing the box to accelerate with the truck.

The direction of the friction force is not always immediately obvious, especially when there are multiple forces acting on an object initially at rest. In such cases, the direction of the tendency to slide must first be determined by finding the direction of the net force, ignoring friction.

Static friction occurs when the surfaces don't move relative to each other. Kinetic friction occurs between two surfaces that are moving relative to each other. Generally, the coefficient of static friction, μ_S, is larger than the coefficient of kinetic friction, μ_k.

Teacher Demonstration

Pull on a block with a spring scale and note the force just before the block moves (force necessary to overcome static friction). As you pull the block slowly across the table, compare the scale readings (kinetic friction).



The coefficient of friction can be defined as:

$$\mu = \left(\frac{F_f}{F_N}\right)$$

SKILLS AND ATTITUDES OUTCOME

S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will…

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

The symbol μ can be thought of as a numerical description of the nature of the surfaces. The equation $\mu = 0$ corresponds to a frictionless surface: small values correspond to two surfaces that are slippery, with the friction becoming larger with larger values of μ.

Note that the equations for friction can then be written as $F_{fk} = \mu_k F_N$ and $F_{fs} = \mu_s F_N$.

Surprisingly, the force of friction only depends on three things, as discussed above (normal force, nature of surfaces, and whether the surfaces are rubbing or forces are attempting to cause rubbing).

The surface area and speed of motion do not generally change the force of friction.

Extension

For inclined planes, identify the normal force relevant to the object experiencing friction. The magnitude of the normal force is generally found using $F_N = m \cdot g \cos\theta$, where θ is the angle between the horizontal and the inclined plane. Gravity exerts a force of $F_a = m \cdot g \sin\theta$ on the object in a direction down the plane. Students can demonstrate that these equations are correct, using vector diagrams and trigonometry.

SUGGESTIONS FOR ASSESSMENT

Research Report/Presentation

Students perform a lab to determine the coefficient of friction for various materials, using the “angle of repose” method.

SUGGESTED LEARNING RESOURCES

Software

Interactive Physics Simulations, Activities #3: Free Fall; #6: Grape Drop

Multimedia

Videodiscs: *Physics at Work*: penny and feather

Video Encyclopedia of Physics Demonstrations: penny and feather

Physics of Flight: motion of free-fall parachutist

General Learning Outcome Connection

Students will…

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

Specific Learning Outcomes

S3P-4-09: Describe terminal velocity, qualitatively and quantitatively.

S3P-4-10: Define the coefficient of friction (μ) as the ratio of the force of friction and the normal force.

S3P-4-11: Distinguish between static and kinetic friction.

S3P-4-12: Compare the effects of the normal force, materials involved, surface area, and speed on the force of friction.

S3P-4-13: Solve problems with the coefficient of friction for objects on a horizontal surface.

Suggestions for Instruction

Student Activity: Coefficient of Static Friction (the following activity could be considered an optional extension)

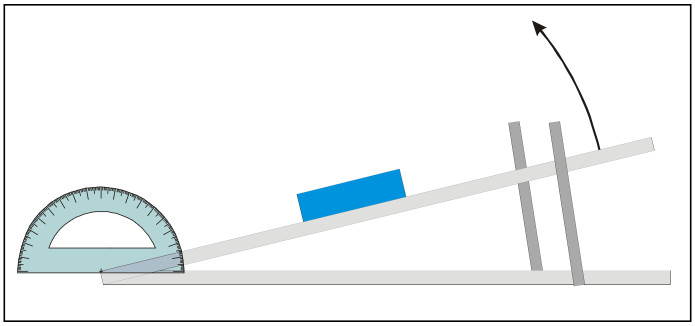
To find the coefficient of static friction, increase the angle of the incline until the object just begins to slide uniformly down the plane (see diagram). At this time, since acceleration is zero:

$F_g = F_f$

$F_f = mg \sin\theta$

And the normal force is the cosine component.

$F_N = mg \cos\theta$



Therefore, the coefficient of friction is

$$\mu = \frac{F_f}{F_N}$$

$$\mu_s = \frac{mg\sin\theta}{mg\cos\theta}$$

$$\mu_s = \frac{\sin\theta}{\cos\theta}$$

$$\mu_s = \tan\theta$$

where θ is the angle of inclination.

SKILLS AND ATTITUDES OUTCOME

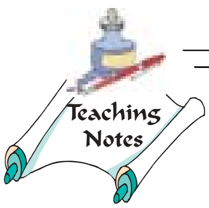
S3P-0-2g: Interpret patterns and trends in data, and infer or calculate linear relationships among variables.

GENERAL LEARNING OUTCOME CONNECTION

Students will...

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



SUGGESTIONS FOR ASSESSMENT

Notes