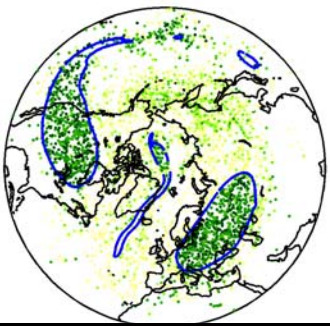
PHYS101-17S1- Engineering Physics A: Mechanics, Waves and Thermal Physics

Material that you will have previously covered in NCEA and/or PHYS111 will be highlighted at the start of each class. You will be expected to understand that material!



Adrian McDonald

Research Interests:
- Understanding Antarctic and Southern Ocean Climate
- Satellite Remote Sensing of the atmosphere and cryosphere
- Climate and weather modelling

What am I trying to teach you? Why does Engineering care about Physics?

- **Physics content/relevant theory:** many engineering problems need a good grounding in Physics theory to be solved, as well as a framework to understand the world!
- **Analytical skills:** Physics also develops your ability to identify important detail and to construct logical and reasoned arguments.
- **Problem solving skills:** solving engineering problems is often about a systematic approach, Physics gives you lots of practice to develop your personal problem solving strategy and learn useful tactics.
- **Applied use of mathematics:** Physics problems give you an opportunity to use mathematical techniques to solve real world problems.
- **Practical Laboratory skills:** Experiment (as well as theory) are at the heart of Physics, PHYS101 gives you hands-on experience and demonstrates best practice.

These are valuable skills! Don't believe me then see: https://www.wired.com/2017/01/move-coders-physicists-will-soon-rule-silicon-valley/

ALL INFORMATION IS IN THE COURSE OUTLINE

Problems or questions email: physics101@canterbury.ac.nz

Note please make the subject line of your email informative.

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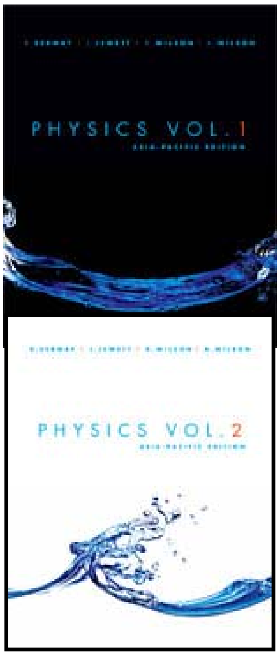
Textbook: Physics Vol. 1 AND Vol. 2: Asia-Pacific Edition by Serway Jewett, Wilson and Wilson



Class Reps?

- Please come and see me at the end if you would like to volunteer!

PHYS101
Mechanics

SJW^2 Chapter 1-10

Material that you will have previously covered in NCEA or equivalents will be highlighted. You will be expected to understand that material!

Lecture 1: Kinematics and Newton's Laws

SJW^2 2.6-2.7, 3.4, 4.2-4.7

All the material in this Lecture is review material and has previously been covered in NCEA (Standard 90521) and/or equivalents

Kinematic Equations

- Describes motion while ignoring the agents that cause the motion.
- The kinematic equations can be used for any particle under **constant acceleration**.

TABLE 2.2

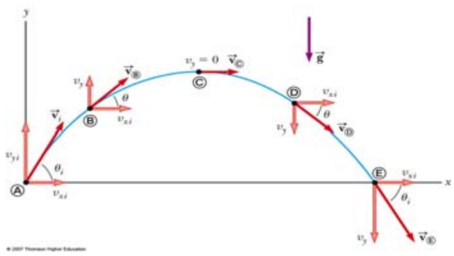
Kinematic Equations for Motion of a Particle Under Constant Acceleration

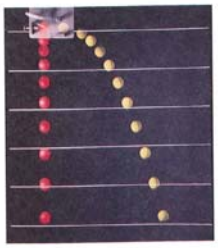
Equation Number	Equation	Information Given by Equation
2.13	$v_{xf} = v_{xi} + a_x t$	Velocity as a function of time
2.15	$x_f = x_i + \frac{1}{2}(v_{xi} + v_{xf})t$	Position as a function of velocity and time
2.16	$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$	Position as a function of time
2.17	$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$	Velocity as a function of position

Note: Motion is along the x axis.

Projectile Motion

- A projectile is an object that moves in two dimensions under the influence of gravity.
- The free-fall acceleration is constant and directed downward over the range of motion. The effect of air friction (or Drag) is negligible.
- With these assumptions, an object in projectile motion will follow a symmetrical parabolic path, called the **trajectory** (see below).
- **Under these assumptions, we may split the problem into independent horizontal and vertical motion components.**





Time-lapse photographs of a ball which is dropped at the same time that a second ball is projected horizontally from the same height. Both reach the ground together.

MYTHBUSTERS : Bullet Fired versus Bullet Dropped

Check understanding 1

From the same height (and at the same time), one ball is dropped and another ball is fired horizontally. Which one will hit the ground first?

1) the “dropped” ball
2) the “fired” ball
3) they both hit at the same time
4) it depends on how hard the ball was fired
5) it depends on the initial height

Check understanding 2

In the previous problem, which ball has the greater velocity at ground level?

1) the “dropped” ball
2) the “fired” ball
3) neither—they both have the same velocity on impact
4) it depends on how hard the ball was thrown

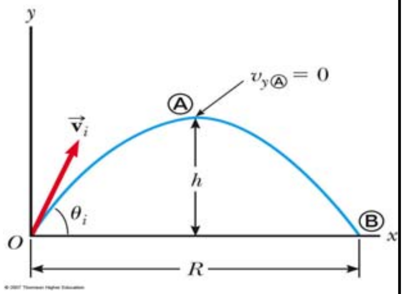
Range and Maximum Height of a Projectile

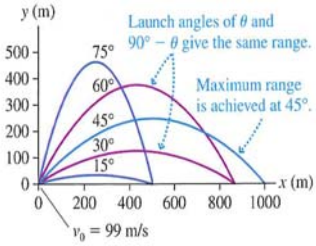
- When analyzing projectile motion, two characteristics are of special interest.
- The range, *R*, is the horizontal distance the projectile travels:

$$R = \frac{v_i^2 \sin 2\theta_i}{g}$$

- The maximum height the projectile reaches is *h:*

$$h = \frac{v_i^2 \sin^2 \theta_i}{2g}$$





Proof

Newton's First Law

Newton's First Law
An object that is not acted on by any outside forces moves at a constant velocity.

SJW² definition:
If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.

Alternative statement
In the absence of external forces, when viewed from an inertial reference frame, an object at rest remains at rest and an object in motion continues in motion with a constant velocity.

Newton's First Law and Inertial frames

- Newton's First Law describes what happens in the absence of a force.
- Also tells us that when no force acts on an object, the acceleration of the object is zero.
- Defines a set of reference frames called inertial frames.
- Any reference frame that moves with constant velocity relative to an inertial frame is also an inertial frame
- A reference frame that moves with constant velocity relative to the distant stars is the best approximation of an inertial frame.
  - We can consider the Earth to be such an inertial frame

Newton's Laws

Newton's Second Law

The force exerted on an object is equal to the product of the object's mass and its acceleration. The acceleration is in the same direction as the force.

SJW² definition:
When viewed from an inertial reference frame, the acceleration of an object is directly proportional to the net force on it and inversely proportional to its mass:

$$\vec{\mathbf{a}} \propto \frac{\sum \vec{\mathbf{F}}}{m} \rightarrow \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

Newton’s Second Law

$$\vec{\mathbf{a}} \propto \frac{\sum \vec{\mathbf{F}}}{m} \rightarrow \sum \vec{\mathbf{F}} = m\vec{\mathbf{a}}$$

- $\sum \vec{\mathbf{F}}$ is the net force and is the vector sum of all the forces acting on the object.
- Newton’s Second Law can be expressed in terms of components as:

  $\Sigma F_x = m\, a_x$
  $\Sigma F_y = m\, a_y$
  $\Sigma F_z = m\, a_z$

  - The SI unit of force is the **Newton** (N)

Newton’s Third Law

Newton’s Third Law:
For every force that one object exerts on a second object there is an equal but oppositely directed force the second object exerts on the first object.

SJW² definition:

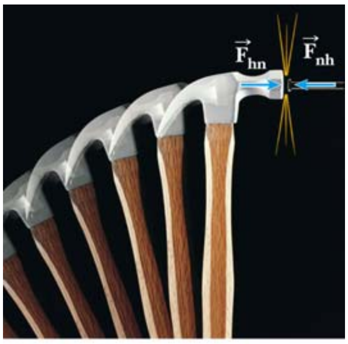
If two objects interact the force $\mathbf{F}_{12}$ exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force $\mathbf{F}_{21}$ exerted by object 2 on object 1.

$$\vec{\mathbf{F}}_{12} = -\vec{\mathbf{F}}_{21}$$

If there is always an equal and opposite force isn’t the net force always zero?

Newton’s Third Law

- Forces always occur in pairs.
- A single isolated force cannot exist.
- The action force is equal in magnitude to the reaction force and opposite in direction.
- **The action and reaction forces must act on different objects.**



(b)

Check Understanding

- A juggler throws two balls up to the same height so that they pass each other halfway up when A is rising and B is descending. Ignore air resistance and buoyant forces. Which statement is true of the two balls at that point?

a) There is an residual upward force from the hand on each ball.

b) There is a greater residual force from the hand on A than there is on B.

c) Only gravity acts on B but there is an additional residual force from the hand on A.

d) There is an additional downwards force besides gravity on each ball.

e) The only force acting on each ball is the gravitational force.

Gravitational Force

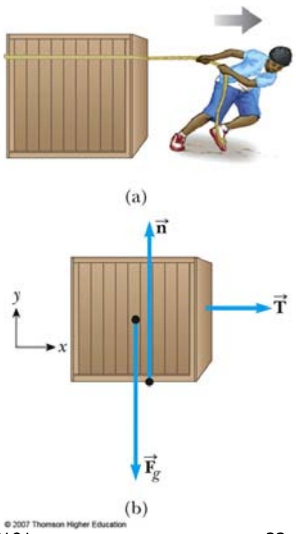
- The gravitational force, $\vec{\mathbf{F}}_g$, is the force that the earth exerts on an object.
- This force is directed toward the center of the earth.
- From Newton's Second Law
  - $$\vec{\mathbf{F}}_g = m\vec{\mathbf{g}}$$
- Its magnitude is called the weight of the object and is *different* than the mass
  - Weight = $F_g = mg$

Free Body Diagrams

- The most important step in solving problems involving Newton's Laws is to draw the free body diagram.
- A free body diagram is a type of force diagram that shows all the forces and only the forces acting on a **single** object.
- Considering a crate being pulled along horizontally on a smooth surface. Forces acting on the crate in the x and y direction:

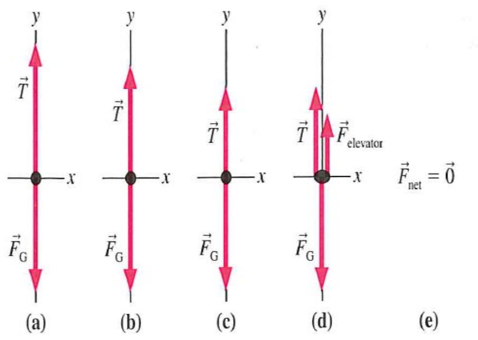
$$\sum F_x = T = ma_x \qquad \sum F_y = n + (-F_g) = 0$$

- Do not assume the normal force equals the weight in every case. If the object is not on a horizontal surface this won't be true.

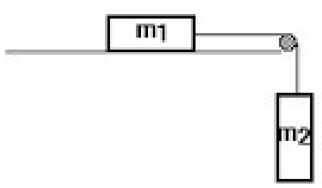


Check Understanding

An elevator suspended from a cable is moving upward and slowing to a stop. Which free-body diagram below is correct?



Practice Example



A simple counterweight system for slowing an elevator's vertical acceleration needs to be designed. This can be visualised as two weights attached to a frictionless, massless pulley.

(a) Draw the free-body diagram for each mass.

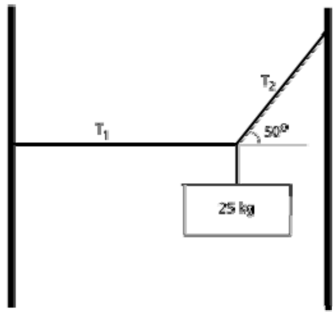
(b) Find the magnitude of acceleration of the weights when m_1 = 200kg and m_2=1200kg.

(c) The rope connecting the pulleys has a breaking tension of 4000N, will it break?

We will complete as many Practice examples as time allows. Students are encouraged to complete these examples in their own time if not completed in class. Model answers will be provided on the LEARN website.

Practice Example

A 25 kg mass is suspended at the end of a horizontal, massless rope that extends from a wall on the left and from the end of a second massless rope connected to a wall on the right at an angle of 50º from the horizontal. What are the tensions in the two ropes?



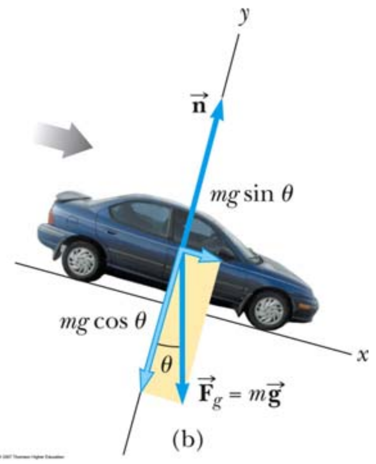
We will complete as many Practice examples as time allows. Students are encouraged to complete these examples in their own time if not completed in class. Model answers will be provided on the LEARN website.

Lecture 2: Newton's Laws and Friction

SJW² 4.7, 5.1

Inclined Planes

- Forces acting on the object:
  - The normal force acts perpendicular to the plane.
  - The gravitational force acts straight down.
- Choose the coordinate system with *x* along the incline and *y* perpendicular to the incline.
- Replace the force of gravity with its components.



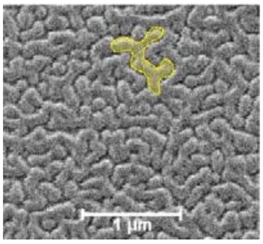
Example: Block on an inclined plane

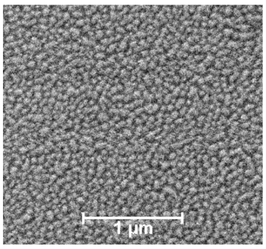
- A block with a mass of 5kg sits on an inclined plane with an angle $\theta=30^o$ from the horizontal.

a. Draw the free-body diagram for the block.
b. Calculate the acceleration of the block down the plane.

Forces of Friction

- When an object is in motion on a surface or through a viscous medium, there will be a resistance to the motion.
  - This is due to electrostatic interactions between the object and the surface.
- This resistance is called *friction.*





Forces of Friction

- **Friction is proportional to the normal force** and there are two types (static and kinetic).

  $f_s \leq \mu_s n$ and $f_k = \mu_k n$

  μ is the **coefficient of friction** and depends on the surfaces in contact.
- **Static friction** acts to keep the object from moving.
- The force of **Kinetic friction** acts when the object is in motion.
- The direction of the frictional force is always opposite to the direction of motion and parallel to the surfaces in contact.

TABLE 5.1

Coefficients of Friction

	μ_s	μ_k
Rubber on concrete	1.0	0.8
Steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
Glass on glass	0.94	0.4
Copper on steel	0.53	0.36
Wood on wood	0.25–0.5	0.2
Waxed wood on wet snow	0.14	0.1
Waxed wood on dry snow	—	0.04
Metal on metal (lubricated)	0.15	0.06
Teflon on Teflon	0.04	0.04
Ice on ice	0.1	0.03
Synovial joints in humans	0.01	0.003

Note: All values are approximate. In some cases, the coefficient of friction can exceed 1.0.

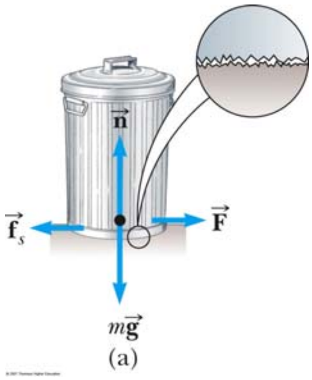
DEMO: Friction boxes.

Static Friction

- **Static friction acts to keep the object from moving.**
- If $\vec{F}$ increases, so does $\vec{f}_s$
- If $\vec{F}$ decreases, so does $\vec{f}_s$

$$f_s \leq \mu_s n$$

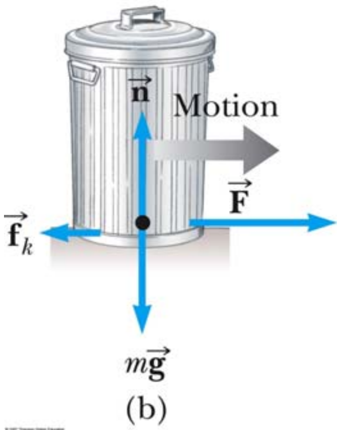
- For static friction, the equal sign is valid only at *impending* motion, the surfaces are on the verge of slipping.
- Use the inequality if the surfaces are not on the verge of slipping.



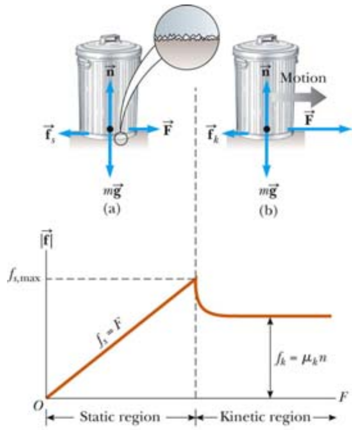
Kinetic Friction

- **The force of Kinetic friction acts when the object is in motion.**
- Although μ_k can vary with speed, we shall neglect any such variations

$$f_k = \mu_k n$$

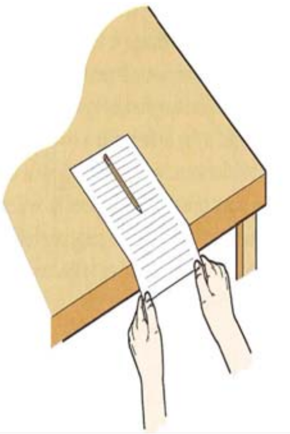


Forces of Friction



PLAY
ACTIVE FIGURE 5.1

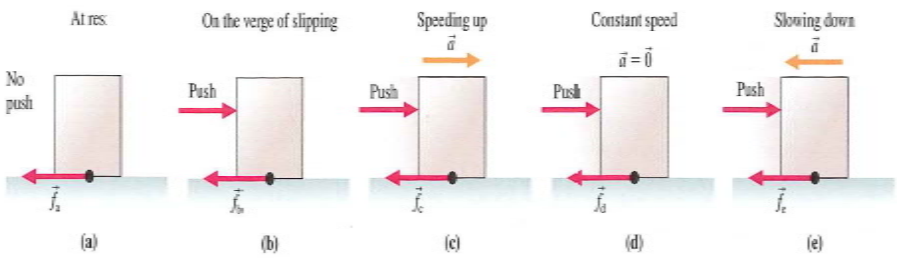
How do Magician's do that trick?



MYTHBUSTERS : Tablecloth Chaos

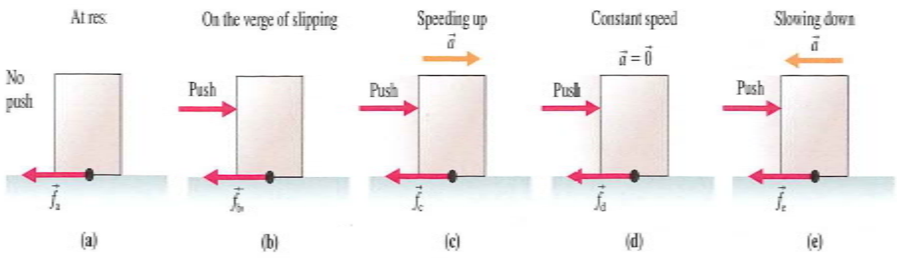
Check Understanding

Rank in order, from largest to smallest, the sizes of the **Static** friction in these 5 situations.



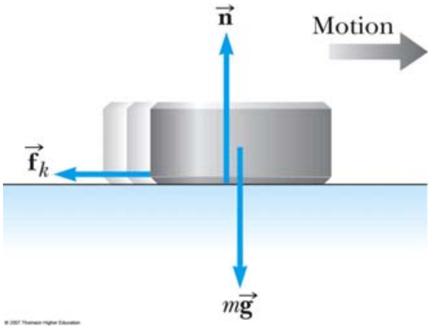
Check Understanding

Rank in order, from largest to smallest, the sizes of the **Kinetic** friction in these 5 situations.



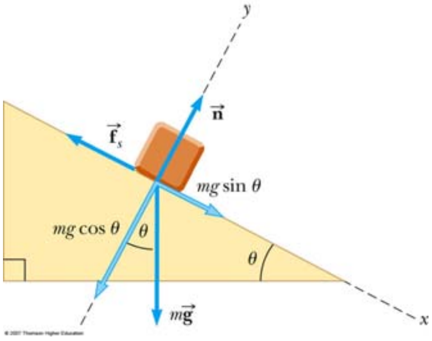
Free-body diagrams including Friction

- Friction is a force, so it must be included when using Newton's Laws
- In a free-body diagram, the force of kinetic friction always opposes the motion and is parallel to the surfaces in contact.



Experimental determination of the coefficient of friction

- The block is sliding down the plane, so friction acts up the plane
- This setup can be used to experimentally determine the coefficient of friction
- $\mu = \tan\theta$
  - For μ_s, use the angle where the block just slips.
  - For μ_k, use the angle where the block slides down at a constant speed.



PLAY
ACTIVE FIGURE 5.6

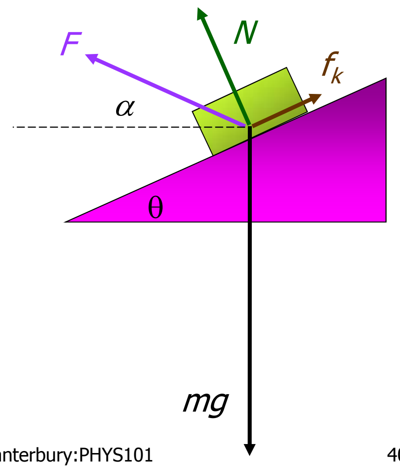
Check Understanding

- **A box sits on a flat board. You lift one end of the board, making an angle with the floor. As you increase the angle, the box will eventually begin to slide down. Why?**

- 1) component of the gravity force parallel to the plane increased
- 2) coefficient of static friction decreased
- 3) normal force exerted by the board decreased
- 4) both #1 and #3
- 5) all of #1, #2, and #3

Practice Example

For a block of mass 5.00 kg being pulled down an inclined plane by a force, F = 20.0 N, applied through a rope at an angle α=30° to the horizontal. For a plane which makes an angle θ=30° with the horizontal and assuming that the coefficient of kinetic friction between the block and the plane is 0.2. Determine the acceleration of the block down the plane?



We will complete as many Practice examples as time allows. Students are encouraged to complete these examples in their own time if not completed in class. Model answers will be provided on the LEARN website.

Practice Example

- You are a road safety engineer and need to identify stopping distance under a set of conditions. Consider a 1500 kg car travelling at a speed of 30 m/s, when the driver applies the brakes and skids to a halt. Determine the stopping distance if the car is travelling up a 10^o slope, down a 10^o slope or on a level road. You may assume that the coefficient of kinetic friction between the car and the road is 0.8.

We will complete as many Practice examples as time allows. Students are encouraged to complete these examples in their own time if not completed in class. Model answers will be provided on the LEARN website.

Lecture 3: Drag and Work

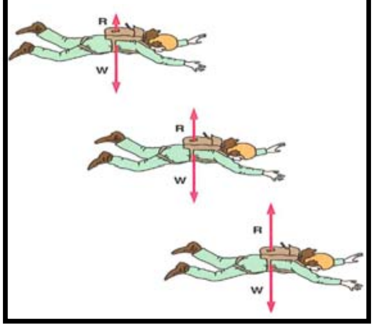
SJW^2 5.2, 6.1-6.3

Some of the material in this Lecture is review material and has previously been covered in NCEA (Standard 90521) and/or equivalents.

Motion with Resistive Forces

- For motion through a fluid, the medium will exert a *resistive force* (or Drag), $\vec{\mathbf{R}}$, on the object moving through the medium.
- The magnitude of the resistive force depends on the medium.
- The direction of the resistive force is always opposite to the direction of motion of the object relative to the medium.

As the skydiver moves towards the Earth, her speed increases and the resistive force gets correspondingly larger. At some point, R and W are balanced and her speed remains constant (terminal speed).



Motion with Resistive Forces 2

- For motion through a fluid, the medium will exert a *resistive force* (or Drag), $\vec{\mathbf{R}}$, on the object moving through the medium.
- The magnitude of the resistive force depends on the medium.
- The direction of the resistive force is always opposite to the direction of motion of the object relative to the medium.

The heavier parachutist must fall faster than the light parachutist for the resistive force to cancel out the greater gravitational force pulling him down.

Motion with Resistive Forces

- The magnitude of $\vec{\mathbf{R}}$ depends on the speed in complex ways
- We will discuss two possibilities
  - $\vec{\mathbf{R}}$ **proportional to v:** Good approximation for small or smooth symmetrical shapes and slow speeds (laminar flow conditions).
  - $\vec{\mathbf{R}}$ **proportional to v²:** Good approximation for large or irregular shapes and fast speeds (turbulent conditions).

TABLE 6.1

Terminal Speed for Various Objects Falling Through Air

Object	Mass (kg)	Cross-Sectional Area (m^2)	v_T (m/s)
Skydiver	75	0.70	60
Baseball (radius 3.7 cm)	0.145	4.2×10^{-3}	43
Golf ball (radius 2.1 cm)	0.046	1.4×10^{-3}	44
Hailstone (radius 0.50 cm)	4.8×10^{-4}	7.9×10^{-5}	14
Raindrop (radius 0.20 cm)	3.4×10^{-5}	1.3×10^{-5}	9.0

Resistive Force Proportional To Speed

- The resistive force can be expressed as:

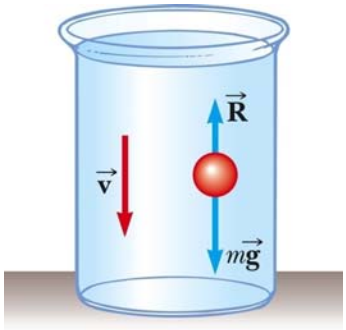
$$\vec{\mathbf{R}} = -b\vec{\mathbf{v}}$$

  - *b* depends on the property of the medium, and on the shape and dimensions of the object/
  - The negative sign indicates that the resistive force is in the opposite direction to the motion.

- Analyzing the motion results:

$$mg - bv = ma = m\frac{dv}{dt}$$

$$a = \frac{dv}{dt} = g - \frac{b}{m}v$$



(a)

PLAY ACTIVE FIGURE 5.13

Terminal Speed

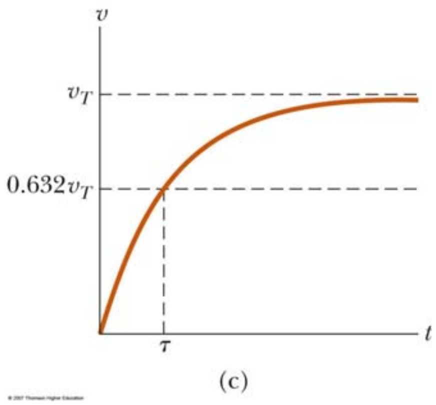
- To find the terminal speed, let $a = 0$

$$v_T = \frac{mg}{b}$$

- Solving the differential equation gives

$$v = \frac{mg}{b}\left(1 - e^{-bt/m}\right) = v_T\left(1 - e^{-t/\tau}\right)$$

- τ is the ***time constant*** and $\tau = m/b$



MYTHBUSTERS : Penny Drop

Check Understanding

What is the net force on a 10-kg solid steel sphere falling in air at terminal speed?

a. 980 N
b. 200 N
c. 98 N
d. 49 N
e. Some value other than those given above

Check Understanding

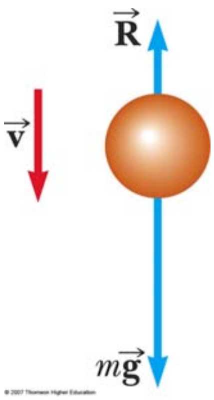
What is the drag force on a 10-kg solid steel sphere falling in air at terminal speed?

a. 980 N
b. 200 N
c. 98 N
d. 49 N
e. Some value other than those given above

Resistive Force Proportional To v^2

- For objects moving at high speeds through air, the magnitude of the resistive force is approximately equal to the square of the speed.

$$R = \tfrac{1}{2} D\rho A v^2$$

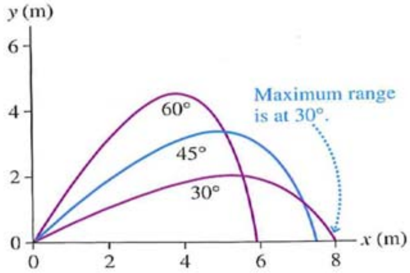


  - D is called the *drag coefficient*
  - ρ is the density of air
  - A is the cross-sectional area of the object
  - v is the speed of the object

Resistive Force Proportional To v^2

- Applying Newton's law of motion to a particle falling through air accounting for air resistance allows us to determine that the terminal speed of such a particle will be:

$$v_T = \sqrt{\frac{2mg}{D\rho A}}$$



Particle trajectory when Drag is accounted for is shown above. Note the differences from a parabolic path.

Proof

Introduction to Energy

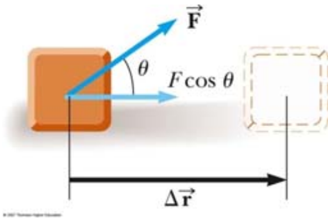
- The concept of energy is one of the most important topics in science and engineering.
- Every physical process that occurs in the Universe involves energy and energy transfers or transformations.
- Energy is not easily defined.
- The energy approach to describing motion is particularly useful when Newton's Laws are difficult or impossible to use.

Work

The work, W, done on a system by an agent exerting a constant force is the product of the magnitude F of the force, the magnitude Δr of the displacement, and cos θ, where θ is the angle between the force and the displacement vectors.

$$W = F\Delta r\cos\theta = \vec{\mathbf{F}}\cdot\Delta\vec{\mathbf{r}}$$

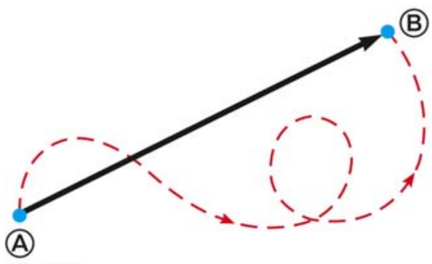
The work done can also be defined as the scalar product (or dot product) of the Force and the displacement vectors.



Vectors and Scalars

- A ***scalar quantity*** is completely specified by a single value with an appropriate unit and has no direction.
  - Distance, speed, time, mass and energy
- A ***vector quantity*** is completely described by a magnitude plus a direction.
  - Displacement, velocity, acceleration, momentum and force.

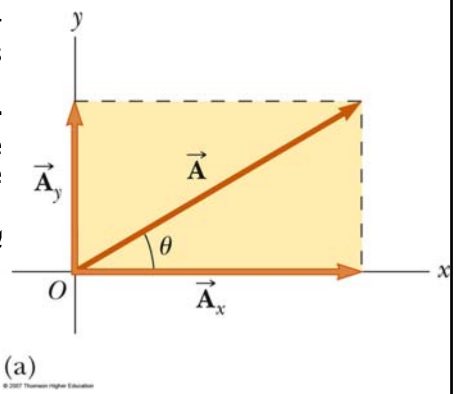
- A particle travels from A to B along the path shown by the dotted red line, this is the ***distance*** traveled and is a scalar.
- The ***displacement*** is the solid line from A to B and is a vector.



Components of a Vector

- A **component** is a projection of a vector along an axis. Any vector can be completely described by its components.
- It is useful to use **rectangular components**. These are the projections of the vector along the x- and y-axes.
- $\vec{\mathbf{A}}_x$ *and* $\vec{\mathbf{A}}_y$ are the ***component vectors*** of $\vec{\mathbf{A}}$

$$\vec{\mathbf{A}} = \vec{\mathbf{A}}_x + \vec{\mathbf{A}}_y$$



Components of a Vector

- The x-component of a vector is the projection along the x-axis.

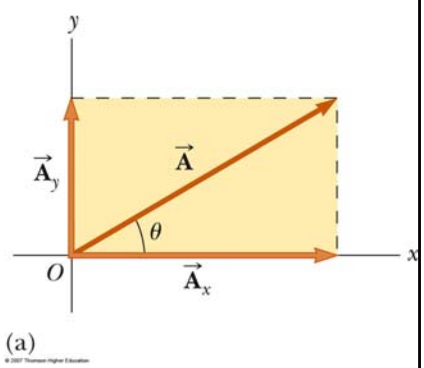
$$A_x = A\cos\theta$$

- The y-component of a vector is the projection along the y-axis.

$$A_y = A\sin\theta$$

- The components are the sides of the right-angled triangle whose hypotenuse is the length of *A* (A is also the magnitude of the vector).

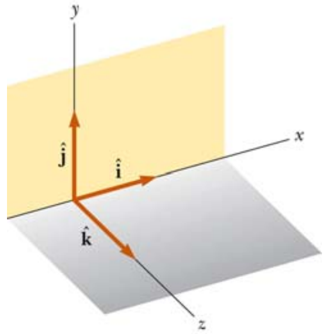
$$A = \sqrt{A_x^2 + A_y^2} \quad \text{and} \quad \theta = \tan^{-1}\frac{A_y}{A_x}$$

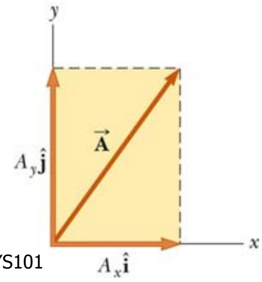


Unit Vectors

- A ***unit vector*** is a dimensionless vector with a magnitude of exactly 1.
- Unit vectors are used to specify a direction and have no other physical significance.
- The symbols $\hat{\mathbf{i}}, \hat{\mathbf{j}}$, and $\hat{\mathbf{k}}$ represent unit vectors in the x, y and z directions.
- They form a set of mutually perpendicular vectors in a right-handed coordinate system.
- $\mathbf{A_x}$ is the same as $A_x\hat{\mathbf{i}}$ and $\mathbf{A_y}$ is the same as $A_y\hat{\mathbf{j}}$ etc.
- The complete vector is

$$\vec{\mathbf{A}} = A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}$$





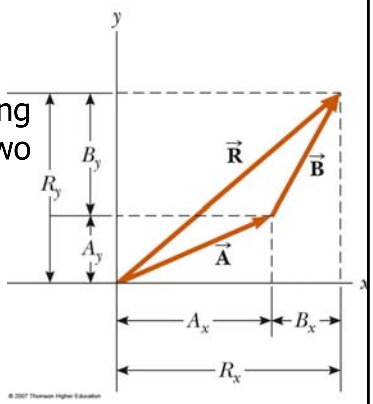
Vector addition

- The vector $\vec{\mathbf{R}}$ can be determined using the components of the other two vectors.

$$\vec{\mathbf{R}} = \left(A_x\hat{\mathbf{i}} + A_y\hat{\mathbf{j}}\right) + \left(B_x\hat{\mathbf{i}} + B_y\hat{\mathbf{j}}\right)$$

$$\vec{\mathbf{R}} = \left(A_x + B_x\right)\hat{\mathbf{i}} + \left(A_y + B_y\right)\hat{\mathbf{j}}$$

$$\vec{\mathbf{R}} = R_x\hat{\mathbf{i}} + R_y\hat{\mathbf{j}}$$



- The magnitude of $\vec{\mathbf{R}}$ and the angle it makes with the x axis can be written as:

$$R = \sqrt{R_x^2 + R_y^2} \qquad \theta = \tan^{-1}\frac{R_y}{R_x}$$

$$R_x = A_x + B_x$$
$$R_y = A_y + B_y$$

Example

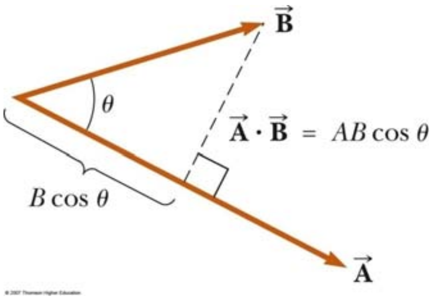
A ball has an acceleration of a= 2.0**i** + 4.0**j** ms^{-2} and an initial velocity of v = 5.0**i** ms^{-1}. Determine the coordinates and speed of the particle at t=5s if at time t=0s the ball is at the origin.

Scalar Product of Two Vectors

- The scalar product of two vectors is written as $\vec{\mathbf{A}} \cdot \vec{\mathbf{B}}$
  - It is also called the dot product

  $$\vec{\mathbf{A}} \cdot \vec{\mathbf{B}} \equiv A\,B\cos\theta$$

  where θ is the angle *between* the two vectors.



- Applied to work, this means $W = F\Delta r\cos\theta = \vec{\mathbf{F}} \cdot \Delta\vec{\mathbf{r}}$

Dot Products of Unit Vectors

$$\hat{\mathbf{i}}\cdot\hat{\mathbf{i}}=\hat{\mathbf{j}}\cdot\hat{\mathbf{j}}=\hat{\mathbf{k}}\cdot\hat{\mathbf{k}}=1$$

$$\hat{\mathbf{i}}\cdot\hat{\mathbf{j}}=\hat{\mathbf{i}}\cdot\hat{\mathbf{k}}=\hat{\mathbf{j}}\cdot\hat{\mathbf{k}}=0$$

- Using component form with vectors:

$$\vec{\mathbf{A}}=A_x\hat{\mathbf{i}}+A_y\hat{\mathbf{j}}+A_z\hat{\mathbf{k}}$$

$$\vec{\mathbf{B}}=B_x\hat{\mathbf{i}}+B_y\hat{\mathbf{j}}+B_z\hat{\mathbf{k}}$$

$$\vec{\mathbf{A}}\cdot\vec{\mathbf{B}}=A_xB_x+A_yB_y+A_zB_z$$

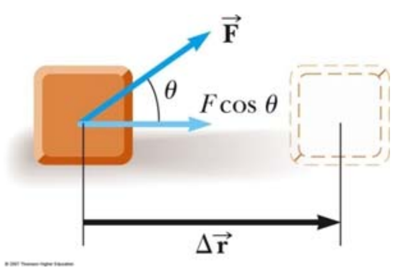
Work

- A force does no work on the object if the force does not produce a displacement.
- The work done by a force on a moving object is zero when the force applied is perpendicular to the displacement.

- **Alternative definition of Work:**

The work done by a given force is the product of the component of the force along the line of motion of the object multiplied by the distance that the object moves under the influence of the force.

$$W=F\Delta r\cos\theta=\vec{\mathbf{F}}\cdot\Delta\vec{\mathbf{r}}$$



More About Work

- The sign of the work depends on the direction of the Force relative to the displacement vector.
- The work done by an applied force is **positive when the projection of the Force vector onto the displacement vector is in the same direction as the displacement.**
- The work done by an applied force is **negative when the projection of the Force vector onto the displacement vector is in the opposite direction as the displacement.**
- **Work is an energy transfer.**
- If W is the work done on a system and W is positive, energy is transferred **to** the system; if W is negative, energy is transferred **from** the system.

Check your understanding

- In a baseball game, the catcher stops a 90-mph pitch. What can you say about the work done by the catcher on the ball?
  - catcher has done positive work
  - catcher has done negative work
  - catcher has done zero work

Work Done By Multiple Forces

- If more than one force acts on a system *and the system can be modeled as a particle*, the total work done on the system is the work done by the net force.

$$\sum W = W_{net} = \int_{x_i}^{x_f} \left(\sum F_x\right) dx$$

- In the general case of a net force whose magnitude and direction may vary, we may write:

$$\sum W = W_{net} = \int_{x_i}^{x_f} \left(\sum \vec{\mathbf{F}}\right) d\vec{\mathbf{r}}$$

- If the system cannot be modeled as a particle, then the total work is equal to the algebraic sum of the work done by the individual forces.

Practice Example

- A skydiver jumps from a plane and falls until he reaches terminal velocity due to air drag. He then opens his parachute which decelerates him further.
  - Draw a labelled graph of the force due to air drag as a function of time.
  - Draw a labelled graph of the speed of the skydiver as a function of time.

  (Note this is also a Past Term Test question)

We will complete as many Practice examples as time allows. Students are encouraged to complete these examples in their own time if not completed in class. Model answers will be provided on the LEARN website.

Practice Example

- A floating ice block is pushed through a displacement of d = (15 m)**i** − (12 m)**j** along a straight embankment by rushing water, which exerts a force F = (210 N)**i**− (150 N)**j** on the block. How much work does the force do on the block during the displacement?

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Practice Example

- A person pulls a 50 kg crate 40 m along a horizontal floor using a constant force of F_P=100 N, which acts at an angle of 37° to the direction of motion. The floor is rough (μ_k=0.3) and exerts an unknown frictional force F_{fr}
- Determine the work done by each force acting on the crate?
- Determine the net work done on the crate?

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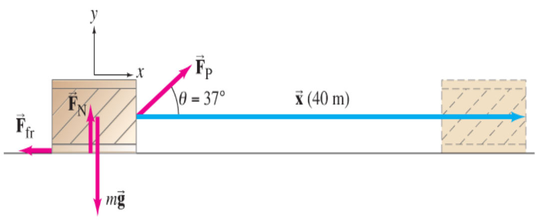

Practice Example

- A solid sphere of explosive m_1= 5kg is placed inside a large hollow spherical shell of mass m_2= 10 kg. The hollow sphere is then dropped from an airplane. The force associated with air drag can be related to the velocity by:

$$F = 0.1v^2$$

where v is the velocity of the hollow sphere. Derive an expression for the force exerted by the solid sphere of explosive on the hollow sphere in terms of velocity. From this expression, sketch a graph of this force as a function of velocity. You know that the explosive will explode if the force reaches 45N, will it explode before it hits the ground?

Practice examples will only be completed in class if the schedule allows. Students are encouraged to complete these examples in their own time and model answers will be provided on the LEARN website.