Explaining Motion:Forces

Chapter Overview (Fall 2002)

A. **Newton's Laws of Motion**

B. **Free Body Diagrams**

C. **Analyzing the Forces and Resulting Motion**

D. **Fundamental Forces**

E. ***Macroscopic* Forces**

F. **Application of Newton's 2nd Law: One Dimension**

G. **Application of Newton's 2nd Law: Two Dimensions**

Chapter Overview (Summer 2003)

A. **Newton's Laws of Motion**

B. **Free Body Diagrams and Application of Newton's 2^{nd} Law: Examples**

C. **Analyzing the Forces and Resulting Motion**

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F. **Application of Newton's 2^{nd} Law: One Dimension**

G. **Application of Newton's 2^{nd} Law: Two Dimensions**

Illustrating Inertia

- Galileo’s rolling ball’s down and incline
- The hanging mass demonstration

Newton's 1st Law: Law of Inertia

Every object continues in its state of rest, or of uniform velocity unless acted upon by an unbalanced, external force.

The converse should also hold. If a change in the state of motion is observed, then an unbalanced force is acting on the object.

Mass and Inertia

Inertia is the tendency of an object to retain its state of motion. Inertia depends on the amount of matter comprising an object.

Mass is a measure of the amount of matter contained in an object. Therefore, mass is a measure of inertia. Mass will be measured in units of kilograms.

Newton's 2nd Law

The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force acting on the object, and is inversely proportional to the mass of the object.

The second law may be expressed through the relationship:

$$\mathbf{a} = \Sigma\mathbf{F}/m$$

$$\Sigma\mathbf{F} = m\,\mathbf{a}$$

Newton's 2^{nd} Law: Comments

Force, like velocity and acceleration is a vector quantity. That is you must know its magnitude and direction to describe it.

The net force is the **vector sum** of all the forces acting on an object and is written as $\Sigma\mathbf{F}$.

The acceleration is always in the direction of the net force.

Forces may originate in a number of different ways (gravity, electrostatic, tension in a rope etc.). Initially however we won't consider the source of the force but instead imagine springs scales are present to record the strength of the force.

Newton's 2nd Law: Comments

- The acceleration of an object is proportional to the net force. There is a linear relationship between acceleration and net force (graph of acceleration versus force would be a straight line)
- The acceleration of an object is inversely proportional to the mass of the object (For a given force, a larger mass will result in a smaller acceleration)

Newton's 2nd Law: Units

$$[\Sigma \mathbf{F}] = [m]\,[\mathbf{a}]$$

$$[\Sigma \mathbf{F}] = \mathbf{kg\ (m/s^2)}$$

$$\mathbf{Newton = kg\ m/s^2}$$

1 Newton is the amount of force needed to give a 1 kg mass an acceleration of 1 m/s^2

Weight

Newton's 3rd Law

If object A exerts a force on object B, object B exerts an equal but opposite force on object A.

$$\mathbf{F}_{AB} = - \mathbf{F}_{BA}$$

Newton's 3rd Law: Comments

Sometimes referred to as the Action-Reaction Law

By Nature, forces exist in pairs

The forces in an action-reaction pair always act on different objects

Normal Force

Applications of Newton's 2nd Law 1D Dynamic

Consider a person standing in an elevator that is accelerating upward. The upward normal force F_N exerted by the elevator floor on the person is

1. **Larger than**
2. **Identical to**
3. **Smaller than**

The downward weight F_g of the person

Newton's 2^{nd} Law 1D Dynamic

An 80 kg person is in an elevator that is accelerating upward at 2 m/s^2. Determine the Normal force acting on the person in the elevator.

Application of Newton's 2nd Law

1)Select the object for analysis

2) Draw Free-Body Diagram for the object (later we will include specific expressions relating the strength of various forces to other parameters)

3) Resolve all vector quantities into their x and y components

4) Solve Newton's 2nd Law for each direction separately

$$(\text{e.g. } \Sigma F_x = m\, a_x)$$

Free Body Diagrams

In Free Body Diagrams, arrows are used to represent each force acting on an object. The arrows are drawn from the center of mass of the object and illustrate the vector nature of the forces acting on an object. The length of the arrow indicates the strength of the force and the direction of the arrow shows the direction of the force.

Free-Body Diagram:Comments

- Anything that is in contact with the object may exert a force on the object (Gravity exerts a force without being in contact).
- If the FBD is *unbalanced*, then the object will accelerate.

Newton's 2nd Law 1D Static

Hugh (90 kg) stands on ice partially supported by a cable around his waste (not neck). The tension in the cable is 250 N. Determine the normal force that the ice exerts on Hugh.

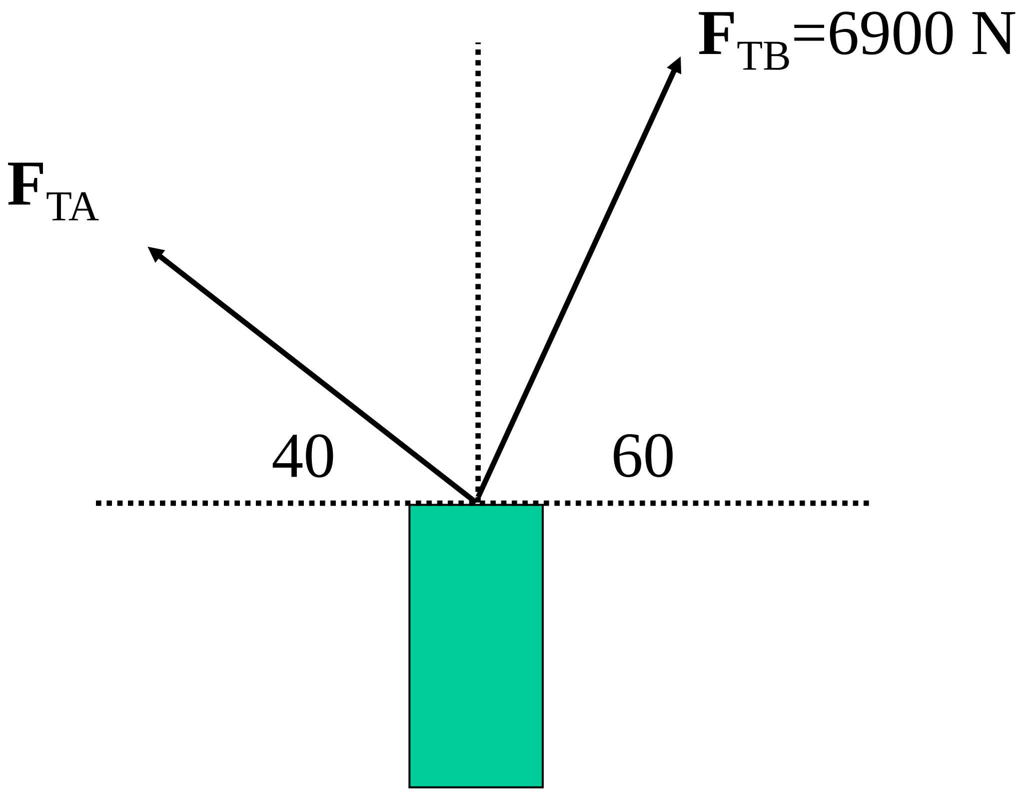
What is the normal force exerted by the ice if the tension increases to 1000 N? What does this mean?

Newton's 2^{nd} Law 1D Dynamic

An elevator car with four people (m=1150 kg) is balanced by a counter weight (m=1000 kg) hanging over a pulley. The motor and braking system stop working. Determine the acceleration of the car. Determine the tension in the cable.

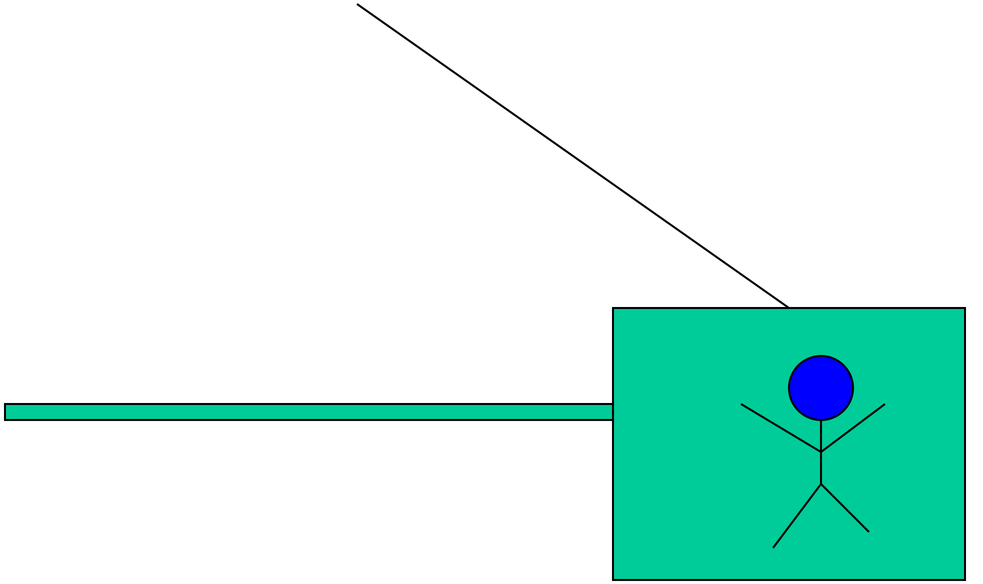
Newton's 2nd Law 2D Dynamic

A sled is being pulled horizontally by two cables as shown (view looking down). Determine the tension needed in cable A to move the object along the y axis. What is the acceleration of the object?



Newton's 2nd Law 2D Static

A 1kg sign is supported by a horizontal rod and a cable that are attached to a building. The cable forms a 55 degree angle upward from the horizontal. Determine the tension in the cable and the force supplied by the rod.



Newton's 3rd Law

The weight of a horse and the normal force exerted by the ground on the horse constitute and interaction pair that are always equal and opposite according to Newton's 3rd Law.

Yes

No

Newton's 2nd Law Dynamic

A 1500 kg car is at rest on an incline (30 degree). What is the maximum acceleration that the car will experience when the break is released?

Free-Body Diagram: Examples

- One-dimension no acceleration: Terminal velocity picture object then FBD
- One-dimension acceleration
- Two-dimension no acceleration: Hanging sign
- Two-dimension with acceleration

Fundamental Forces of Nature

Gravity

Electromagnetic

Weak Nuclear (Electroweak?)

Strong Nuclear

Newton's Universal Law of Gravitation

Figure

$$mag(\vec{F}_g) = F_g = G\frac{m_1 m_2}{r^2}$$

Newton's Universal Law of Gravitation: Comments

In the figure below an object 1 (of mass m1) exerts an attractive force F21 on an object 2 (of mass m2). Similarly object 2 exerts a force F12 on object 1. By Newton's 3rd Law these forces are equal in magnitude but opposite in direction.

Macroscopic Forces

Force Due to Gravity II: Weight

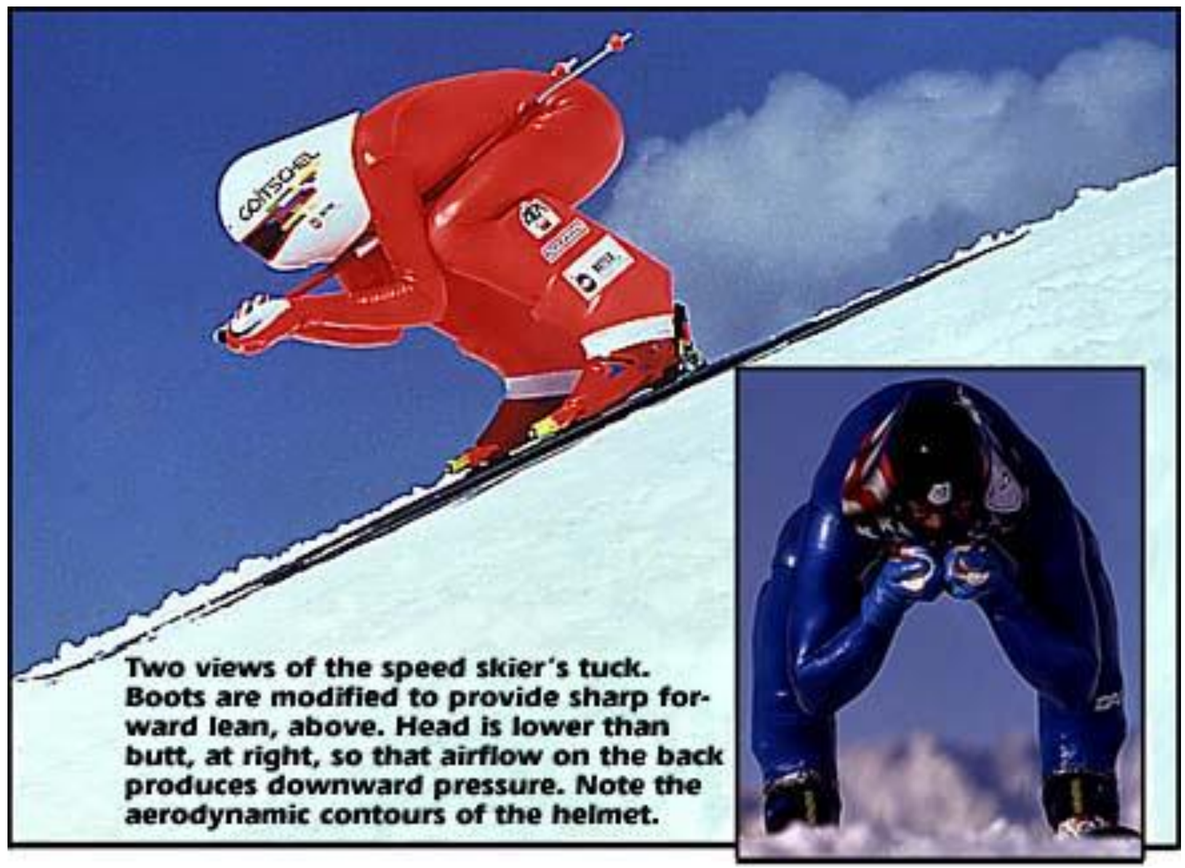
Normal Force

Tension

Friction

Applications 2D

A skier has just begun descending a 30 degree slope. Assuming that the coefficient of kinetic friction is .10 calculate her acceleration and speed after 10 seconds.



The Rotor

In an amusement park ride, a small child (m = 30 kg) stands against the wall of a cylindrical room that is then made to rotate. The floor drops downward and the child remains pinned against the wall. The radius of the device is 2.15 m. A frictional force between the child and the wall keeps the child from falling. The coefficient of friction between the child and the wall is 0.400. At what speed must the child rotate to keep from slipping down the wall.

The Rotor

HOMEWORK #7

Chapter 5

Questions 6 and 12

Problems 2, 10, 13, 17, 19, 23, 33

Recommended Problems 5, 8, 16, 18

Compare the maximum speeds at which a car can safely negotiate an unbanked turn (r =50.0 m) in dry weather (µs = .9) and icy weather (µs = .1)

- A car goes around a tight curve (radius of 50 m) at a speed of 15 m/s. At what angle must the curve be banked so that the car can safely negotiate the curve in the absence of friction?

http://galileo.phys.virginia.edu/classes/109N/more_stuff/Applets/newt/newtmtn.html

Work and Energy

- **Work: Effort exerted to accomplish a task (achieve a goal)**

In physics, the effort exerted is the force (individual or net) applied to an object.

In physics, the achievement is the displacement of the object.

Only the component of the force in the direction of the motion does work.

$$W = F \Delta r \cos(\theta)$$

Work and Energy: Observations

- Work is a scalar quantity
- Work puts “energy” into or takes “energy” out of a system (which may be an object)
- Each force acting on an object may do work the sum of each force’s work is the net work
- Or we may find the net force (some of the forces) which does net work on the object
- The net work done on a stationary object or one moving at constant SPEED is zero

Work Energy Modified

A skier (m=70 kg) gliding along a flat surface with a speed of 12 m/s approaches an 18 incline 12.2 m in length. She stops as she reaches the top of the incline. Determine the work done by the frictional force and the frictional force

Conservation of Mechanical Energy

A ball of mass m =2.60 kg, starting from rest, falls a vertical distance of .55 cm before striking a vertical coiled spring which subsequently compresses by .15 m. What is the spring constant of the spring?

$$\vec{p} = m\vec{v}$$

$$\Delta\vec{p} = \int \vec{F}_{\substack{net \\ external}} dt = \vec{F}_{average}\Delta t$$

$$\vec{p}_{initial} = \vec{p}_{final}$$

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

$$\frac{1}{2} m_1 v_{1i}^2 + \frac{1}{2} m_2 v_{2i}^2 = \frac{1}{2} m_1 v_{1f}^2 + \frac{1}{2} m_2 v_{1f}^2$$

$$v_{1i} - v_{2i} = -(v_{1f} - v_{2f})$$

The combination of Conservation of Momentum and Energy for a two body elastic collision yields (last class)

$$v_{1i} - v_{2i} = -(v_{1f} - v_{2f})$$

Conservation of Momentum for a two body elastic collision

$$m_1 v_{1i} + m_2 v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

During a rainstorm 0.060 kg/s of water strikes the roof of a car at a speed of 15 m/s. Assuming the rain rebounds from the roof at a speed of 5 m/s, what is the force exerted by the rain on the roof in 1 s?