Physics 207, Lecture 6, Sept. 22

● Goals:

  ❖ Recognize different types of forces and know how they act on an object in a particle representation

  ❖ Identify forces and draw a Free Body Diagram

  ❖ Solve 1D and 2D problems with forces in equilibrium and non-equilibrium (i.e., acceleration) using Newton’s 1st and 2nd laws.

  ❖ Know what an IRD is and how it relates to Newton’s Laws

Assignment: HW3, (Chapters 4 & 5, due 9/25, Wednesday)
Read up through Chapter 7, Section 5
1st Exam Thursday, Oct. 2nd from 7:15-8:45 PM Chapters 1-7

Newton’s First Law and IRFs

An object subject to no external forces moves with constant velocity if viewed from an inertial reference frame (IRF).

If no net force acting on an object, there is no acceleration.

● The above statement can be used to define inertial reference frames.
IRFs

- An IRF is a reference frame that is not accelerating (or rotating) with respect to the “fixed stars”.

- If one IRF exists, infinitely many exist since they are related by any arbitrary constant velocity vector!

- In many cases (i.e., Chapters 5, 6 & 7) the surface of the Earth may be viewed as an IRF

Newton’s Second Law

The acceleration of an object is directly proportional to the net force acting upon it. The constant of proportionality is the mass.

\[ \sum \vec{F} = \vec{F}_{\text{NET}} = m \vec{a} \]

- This expression is vector expression: \( F_x, F_y, F_z \)

- Units
  - The metric unit of force is kg m/s\(^2\) = Newtons (N)
  - The English unit of force is Pounds (lb)
Example Non-contact Forces

All objects having mass exhibit a mutually attractive force (i.e., gravity) that is distance dependent

At the Earth’s surface this variation is small so little “g” (the associated acceleration) is typically set to 9.80 or 10. m/s²

Contact (i.e., normal) Forces

Certain forces act to keep an object in place. These have whatever force needed to balance all others (until a breaking point).
No net force $\rightarrow$ No acceleration

$$\sum \vec{F} = \vec{F}_{\text{net}} = m \vec{a} = 0$$

(Force vectors are not always drawn at contact points)

$$\sum F_x = 0$$

$$\sum F_y = 0$$

$\vec{F}_{B,T}$ Normal force is always $\perp$ to a surface

$$\sum F_y = -mg + N = 0$$

$$N = mg$$

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No net force $\rightarrow$ No acceleration

$$\sum \vec{F} = \vec{F}_{\text{net}} = m \vec{a} = 0$$

- If zero velocity then “static equilibrium”
- If non-zero velocity then “dynamic equilibrium”
- This label depends on the observer

- Forces are vectors

$$\sum \vec{F} \equiv \vec{F}_{\text{net}} = m \vec{a} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots$$
A special contact force: Friction

- What does it do?
  - It opposes motion (velocity, actual or that which would occur if friction were absent!)

- How do we characterize this in terms we have learned?
  - Friction results in a force in a direction opposite to the direction of motion (actual or, if static, then “inferred”!)

Friction...

- Friction is caused by the “microscopic” interactions between the two surfaces:
Friction...

- Force of friction acts to **oppose** motion:
  - Parallel to a surface
  - Perpendicular to a **Normal** force.

Static Friction with a bicycle wheel

- You are pedaling hard and the bicycle is speeding up.
  What is the direction of the frictional force?

- You are breaking and the bicycle is slowing down
  What is the direction of the frictional force?
Important notes

- Many contact forces are conditional and, more importantly, they are not necessarily constant.

- We have a general notion of forces is from everyday life.

- In physics the definition must be precise.
  - A force is an action which causes a body to accelerate.

  (Newton’s Second Law)

- On a microscopic level, all forces are non-contact.

Pushing and Pulling Forces

- A rope is an example of something that can pull.
- You arm is an example of an object that can push or push.
Examples of Contact Forces: A spring can push

**FIGURE 5.4** The spring force.

A compressed spring exerts a pushing force on an object.

![Diagram showing a spring pushing an object](image)

A spring can pull

A stretched spring exerts a pulling force on an object.

![Diagram showing a spring pulling an object](image)
Ropes provide tension (a pull)

**FIGURE 5.6** An atomic model of tension.

In physics we often use a “massless” rope with opposing tensions of equal magnitude

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**Forces at different angles**

Case 1: Downward angled force with friction
Case 2: Upwards angled force with friction
Cases 3, 4: Up against the wall
Questions: Does it slide?
What happens to the normal force?
What happens to the frictional force?
Free Body Diagram

A heavy sign is hung between two poles by a rope at each corner extending to the poles.

A hanging sign is an example of static equilibrium (depends on observer)
What are the forces on the sign and how are they related if the sign is stationary (or moving with constant velocity) in an inertial reference frame?

Free Body Diagram

Step one: Define the system

Step two: Sketch in force vectors
Step three: Apply Newton’s 2\textsuperscript{nd} Law
(Resolve vectors into appropriate components)
Free Body Diagram

Vertical:
- y-direction: \[ 0 = -mg + T_1 \sin \theta_1 + T_2 \sin \theta_2 \]

Horizontal:
- x-direction: \[ 0 = -T_1 \cos \theta_1 + T_2 \cos \theta_2 \]

Exercise, Newton's 2nd Law

A woman is straining to lift a large crate, without success. It is too heavy. We denote the forces on the crate as follows:

- \( P \) is the upward force being exerted on the crate by the person
- \( C \) is the contact force on the crate by the floor, and
- \( W \) is the weight (force of the earth on the crate).

Which of following relationships between these forces is true, while the person is trying unsuccessfully to lift the crate? (Note: force up is positive & down is negative)

A. \( P + C < W \)
B. \( P + C > W \)
C. \( P = C \)
D. \( P + C = W \)
Mass

- We have an idea of what mass is from everyday life.
- In physics:
  - Mass (in Phys 207) is a quantity that specifies how much inertia an object has (i.e. a scalar that relates force to acceleration) (Newton’s Second Law)
  - Mass is an inherent property of an object.
  - Mass and weight are different quantities; weight is usually the magnitude of a gravitational (non-contact) force.
  - “Pound” (lb) is a definition of weight (i.e., a force), not a mass!

Inertia and Mass

- The tendency of an object to resist any attempt to change its velocity is called Inertia.
- Mass is that property of an object that specifies how much resistance an object exhibits to changes in its velocity (acceleration)

If mass is constant then \( \vec{a} \propto \vec{F}_{\text{net}} \)

If force constant \( \rightarrow \) \( |\vec{a}| \propto \frac{1}{m} \)

- Mass is an inherent property of an object
- Mass is independent of the object’s surroundings
- Mass is independent of the method used to measure it
- Mass is a scalar quantity
- The SI unit of mass is kg
Exercise
Newton’s 2nd Law

- An object is moving to the right, and experiencing a net force that is directed to the right. The magnitude of the force is decreasing with time (read this text carefully).

- The speed of the object is

A. increasing  
B. decreasing  
C. constant in time  
D. Not enough information to decide

Home Exercise
Newton’s 2nd Law

A constant force is exerted on a cart that is initially at rest on an air table. The force acts for a short period of time and gives the cart a certain final speed $s$.

In a second trial, we apply a force only half as large.

To reach the same final speed, how long must the same force be applied (recall acceleration is proportional to force if mass fixed)?

A. 4 x as long  
B. 2 x as long  
C. 1/2 as long  
D. 1/4 as long
Home Exercise Newton’s 2nd Law
Solution

\[ F = ma \]

Since \( F_2 = \frac{1}{2} F_1 \) \( \Rightarrow a_2 = \frac{1}{2} a_1 \)

We know that under constant acceleration, \( v = a \Delta t \)

So,
\[
a_2 \Delta t_2 = a_1 \Delta t_1 \quad \text{we want equal final velocities}
\]
\[
\frac{1}{2} a_1 / \Delta t_2 = a_1 / \Delta t_1
\]
\( \Delta t_2 = 2 \Delta t_1 \)

(B) 2 x as long

Home Exercise
Newton’s 2nd Law

A force of 2 Newtons acts on a cart that is initially at rest on an air track with no air and pushed for 1 second. Because there is friction (no air), the cart stops immediately after I finish pushing. It has traveled a distance, \( D \).

Next, the force of 2 Newtons acts again but is applied for 2 seconds.

The new distance the cart moves relative to \( D \) is:

A. 8 x as far
B. 4 x as far
C. 2 x as far
D. 1/4 x as far
**Home Exercise Solution**

We know that under constant acceleration,
\[ \Delta x = a \left( \frac{\Delta t}{2} \right)^2 \]  
(when \( v_0 = 0 \))

Here \( \Delta t_2 = 2\Delta t_1 \), \( F_2 = F_1 \) \( \Rightarrow \) \( a_2 = a_1 \)

\[
\frac{\Delta x_2}{\Delta x_1} = \frac{1}{2} \frac{a\Delta t_2^2}{a\Delta t_1^2} = \frac{(2\Delta t_1)^2}{\Delta t_1^2} = 4
\]

(B) 4 x as long

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**Exercise**

Newton’s 2\(^{nd}\) Law

A 10 kg mass undergoes motion along a line with a velocities as given in the figure below. In regards to the stated letters for each region, in which is the magnitude of the force on the mass at its greatest?

A. B
B. C
C. D
D. F
E. G

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Exercise: Physics in an Elevator
Gravity and Normal Forces

A woman in an elevator is accelerating upwards

The normal force exerted by the elevator on the woman is,
(A) greater than
(B) the same as
(C) less than
the force due to gravity acting on the woman
(REMEMBER: Draw a FREE BODY DIAGRAM)

Moving forces around

- Massless strings: Translate forces and reverse their
direction but do not change their magnitude
(we really need Newton’s 3\textsuperscript{rd} of action/reaction to justify)

\[ |T_1| = |-T_1| = |T_2| = |-T_2| \]
Scale Problem

- You are given a 1.0 kg mass and you hang it directly on a fish scale and it reads 10 N (g is 10 m/s²).

- Now you use this mass in a second experiment in which the 1.0 kg mass hangs from a massless string passing over a massless, frictionless pulley and is anchored to the floor. The pulley is attached to the fish scale.

- What force does the fish scale now read?

Scale Problem

- Step 1: Identify the system(s).
  In this case it is probably best to treat each object as a distinct element and draw three force body diagrams.
  - One around the scale
  - One around the massless pulley (even though massless we can treat is as an “object”)
  - One around the hanging mass

- Step 2: Draw the three FBGs. (Because this is a now a one-dimensional problem we need only consider forces in the y-direction.)
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Scale Problem

\[ \Sigma F_y = 0 \text{ in all cases} \]

1: \[ 0 = -2T + T' \]
2: \[ 0 = T - mg \rightarrow T = mg \]
3: \[ 0 = T'' - W - T' \] (not useful here)

\[ T = 2mg = 20 \text{ N} \]
(We start with 10 N but end with 20 N)

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Read rest of chapter 6 and chapter 7 (through section 5)