Lecture 6

- Chapter 5 and 6 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 IRF is and how it relates to Newton’s Laws

Assignment: HW3, (Chapters 4 & 5, due 2/11, Wednesday) Finish reading Chapter 6
Exam 1 Wed, Feb. 18 from 7:15-8:45 PM Chapters 1-7

Relative motion and frames of reference

- Reference frame $S$ is stationary
- Reference frame $S'$ is moving at $v_o$
- This also means that $S$ moves at $-v_o$ relative to $S'$
- Define time $t = 0$ as that time when the origins coincide

Relative Velocity

- The positions, $r$ and $r'$, as seen from the two reference frames are related through the velocity, $v_o$, where $v_o$ is velocity of the $r'$ reference frame relative to $r$
  - $r' = r - v_o \Delta t$
- The derivative of the position equation will give the velocity equation
  - $v' = v - v_o$
- These are called the Galilean transformation equations
- Reference frames that move with “constant velocity” (i.e., at constant speed in a straight line) are defined to be inertial reference frames (IRF); anyone in an IRF sees the same acceleration of a particle moving along a trajectory.
  - $a' = a$ (differentiation of $v = v(t)$)

Central concept for problem solving: “$x$” and “$y$” components of motion treated independently.

- Example: Man on cart tosses a ball straight up in the air.
- You can view the trajectory from two reference frames:
  - $y(t)$ motion governed by
    1) $a = -g$
    2) $v_y = v_{y_0} - g \Delta t$
    3) $y = y_{0y} + v_{0y} \Delta t - \frac{1}{2} g \Delta t^2$
  - $x$ motion: $x = v_{0x} t$

Net motion: $R = x(t) \hat{i} + y(t) \hat{j}$ (vector)

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.

What causes motion? (Actually changes in motion)

What are forces?

What kinds of forces are there?

How are forces and changes in motion related?
Physics 207 – Lecture 6

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/s\(^2\)

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)

- Normal force is always \( \perp \) to a surface

\[ \sum F_y = -mg + N = 0 \]

\[ N = mg \]

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”)

\[
\begin{align*}
F_{\text{APPLIED}} & \quad \text{ma} \\
F_{\text{FRICTION}} & \quad mg
\end{align*}
\]

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.

\[
\begin{align*}
F & \quad \text{ma} \\
f_{f} & \quad mg
\end{align*}
\]

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 pull
Examples of Contact Forces:
A spring can push

**FIGURE 5.4** The spring force.

A compressed spring exerts a pushing force on an object.

(a) $f_{sp}$

A spring can pull

**FIGURE 5.5** A stretching spring exerts a pulling force on an object.

(b) $f_{sp}$

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.

Ropes provide tension (a pull)

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

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.

**Eat at Bucky's**

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

**Eat at Bucky's**

Step two: Sketch in force vectors

Step three: Apply Newton's 2nd Law
(Resolve vectors into appropriate components)
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 a 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

Exercise, Newton's 2nd Law

A woman is trying to lift a large crate, without success. It is too heavy. We deline 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 the 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. $P + C = W$

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

Page 5
Physics 207 – Lecture 6

Home Exercise Newton’s 2nd Law
Solution

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

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 3rd of action/reaction to justify)
- Massless, frictionless pulleys: Reorient force direction but do not change their magnitude

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$-T_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_2$</td>
<td>$-T_2$</td>
</tr>
<tr>
<td>$</td>
<td>T_1</td>
</tr>
</tbody>
</table>
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 \( \text{m/s}^2 \)).

- 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?

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

1: \( 0 = -2T + T' \)

2: \( 0 = T - mg \rightarrow T = mg \)

3: \( 0 = T' - W - T' \) (not useful here)

- Substituting 2 into 1 yields \( T' = 2mg = 20 \text{ N} \)
  (We start with 10 N but end with 20 N).

Lecture 6

Assignment: HW3, (Chapters 4 & 5, due 2/11, Wednesday)
Read rest of chapter 6