Lecture 7

Goals:
- Analyze motion in different frames of reference (non-accelerated)
- Identify the types of forces
- Distinguish Newton’s Three Laws of Motion
- Use a Free Body Diagram to solve 1D and 2D problems with forces in equilibrium and non-equilibrium (i.e., acceleration) using Newton’s 1st and 2nd laws.

1st Exam Monday, Feb. 20 7:15-8:45 PM Chapters 1-4
2103 Chamberlin Hall (M. Tobin, A. Chehade, T. Sinensky)
Sections: 604, 605, 606, 609, 610, 611
Room Change B102 Van Vleck (E. Poppenheimer, Z. Dong, D. Crow)
Sections: 602, 603, 607, 608, 612

Relative motion and reference frames?

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Relative motion and frame of reference

1. Reference frame \( S \) is stationary (with origin \( O \))
2. Reference frame \( S' \) is moving at \( v_o \) (with origin \( O' \))
3. This also means that \( S \) moves at \(-v_o\) relative to \( S' \)
4. Define time \( t = 0 \) as that time when the origins coincide

Relative velocity

1. 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 \( r \)
   \[ r' = r - v_o t \]
2. The derivative of the position equation will give the velocity equation
   \[ v = \frac{dr}{dt} = \frac{dr'}{dt} \]
3. These are called the Galilean transformation equations

x and y motions are independent

1. Example: Man on cart tosses a ball straight up in the air.
2. You can view the trajectory from two reference frames:
   - Reference frame on the moving cart
     \[ a = -g \]
     \[ v_t = v_0_y - gt \]
     \[ y = y_0 + v_0_y - g t^2/2 \]
   - Reference frame on the ground
     \[ x = v_x t \]
     \[ y = 0 \]
Exercise, Relative Trajectories: Monkey and Hunter

All free objects, if acted on by gravity, accelerate similarly.

A hunter sees a monkey in a tree, aims his gun at the monkey and fires. At the same instant the monkey lets go.

Does the bullet ...

a. go over the monkey.

b. hit the monkey.

c. go under the monkey.

Exercise, Relative Motion

1. You are swimming across a 50. m wide river in which the current moves at 1.0 m/s with respect to the shore. Your swimming speed is 2.0 m/s with respect to the water.

You swim perfectly perpendicular to the current, how fast do you appear to be moving to an observer on shore?

\[
\vec{v} = 1 \text{ m/s } \hat{i} + 2 \text{ m/s } \hat{j}
\]

\[
|\vec{v}| = \sqrt{1.0^2 + 2.0^2} \text{ m/s} = 2.2 \text{ m/s}
\]

Chap 5

What causes motion?

What kinds of forces are there?

How are forces & changes in motion related?
What are forces and how do they relate to motion?

- Aristotle: Continuation of motion depends on continued action of a force.

- Newton: An object in motion will remain in motion (i.e., with constant velocity) unless acted upon by a force.

Was Aristotle wrong?

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 external 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”.

- In many cases the surface of the Earth is considered to approximate an IRF

Forces are vectors

- Forces have magnitudes and direction

- SI unit of force is the kg meter/second² or Newton

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 (e.g., “normal”) Forces

Certain forces act to keep an object in place. These have whatever force needed to balance all others (until a breaking point).

Here: A contact force from the table opposes gravity, Normal forces are always perpendicular to a surface.
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Force is a vector quantity
No net force → No acceleration

\[ \sum \vec{F} = \vec{F}_{\text{net}} = 0 \Rightarrow \vec{a} = 0 \]

- If zero velocity then "static equilibrium"
- If non-zero velocity then "dynamic equilibrium"
- If more than one external force acts, vector addition

\[ \sum \vec{F} \equiv \vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots \]

Newton’s Second Law
The acceleration of an object is directly proportional to the net external force acting upon it.
The constant of proportionality is the mass.

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

- This is a vector expression

\[ \vec{F} = F_x \hat{i} + F_y \hat{j} + F_z \hat{k} \]

\[ F_{\text{NET}_x} = ma_x \]

\[ F_{\text{NET}_y} = ma_y \]

\[ F_{\text{NET}_z} = ma_z \]

Newton’s 3rd Law
1. For every action there is an equal and opposite reaction.

1. The 3rd Law requires two objects. If a force from one object acts on a second object then a second force (equal in magnitude and opposite in direction) acts on the second object.

1. Newton’s 1st and 2nd Laws pertain to just a single object or system.

Example
Consider the forces on an object undergoing projectile motion
These are force pairs (3rd Law)

\[ F_{\text{B.E}} = -m_b g \]

\[ F_{\text{E.T}} = m_b g \]

This is NOT a force pair

Measuring Forces
1. Hanging scales

1. Floor scales
Moving forces around

- Massless strings: Translate forces and reverse their direction but do not change their magnitude

- Massless, frictionless pulleys: Reorient force direction but do not change their magnitude

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

High Tension

- A crane is lowering a load of bricks on a pallet. A plot of the position vs. time is shown.
- There are no frictional forces.
- Compare the tension in the crane’s wire (T) at the point it contacts the pallet to the weight (W) of the load (bricks + pallet).

A: \( T > W \)  
B: \( T = W \)  
C: \( T < W \)  
D: don’t know

Newton’s 2nd Law, Forces are conditional

A woman is trying to lift a large crate, with no 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 or normal 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. \( P + C = W \)

Analyzing Forces: 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 2nd Law
(Resolve vectors into appropriate components)
Scale Problem

1. You are given a 5.0 kg mass and you hang it directly on a fish scale and it reads 50 N (g is 10 m/s²).

2. Now you use this mass in a second experiment in which the 5.0 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.

3. What force does the fish scale now read?

What will the scale read?

A  25 N  
B  50 N  
C  75 N  
D  100 N  
E  something else

Fini

Next Tuesday….all of Chapter 5

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