Lect. 7, Chapter 4: Newton’s Laws

Today: The 1st Law; the 2nd Law; Mass, forces.

About Midterm Exam 1

- When and where
  - Thurs. Feb. 17th 5:45-7:00 pm
  - Rooms: See course webpage. Be sure to report to your TA's room.
  - Your TA will give a review during the discussion session next week.

- Format
  - Closed book, 20 multiple-choice questions (consult with practice exam)
  - 1 page 8x11 formula sheet allowed, must be self-prepared, no photocopying/download-printing of solutions, lecture slides, etc.
  - Bring a calculator (but no computer). Only basic calculation functionality can be used. Bring a 2B pencil for Scantron.
  - Fill in your ID and section #!

- Special requests:
  - Email me at than@hep.wisc.edu, w/ valid excuse for approval.
  - One alternative exam: 3:30pm – 4:45pm, Thurs Feb. 17, in our 201 lab rm.

So far, we learnt “kinematics”:

- Motion of an object: position, velocity, and acceleration

First Law:
An object at rest stays at rest unless acted on by an external force. An object in motion continues to travel with constant speed in a straight line unless acted on by an external force.

- Another way to say the same thing: Law of Inertia
  - When no net force,
    - velocity is constant
    - acceleration is zero
  → All in vector form!

Is Madison a good inertial reference frame?

- Is Madison accelerating?
  - YES!
  - Madison is on the earth.
  - The earth is rotating.

What is the centripetal acceleration of Madison?

\[ a_M = \frac{v^2}{R} = \frac{v^2}{R_E} = \frac{2\pi R}{T} \]

Plug this in: \( a_M = 0.034 \text{ m/s}^2 \approx 1/300 \text{ g} \)

This is close enough to zero that we ignore it in practice.

Madison is a pretty good inertial reference frame.
A Force

An external influence or action on an object, that causes the object to change velocity.

Force is a vector:

If two or more forces simultaneously act on an object, the net force is equal to the vector sum of the individual forces.

Question 1

An airplane is flying from Willard airport to O'Hare. Many forces act on the plane, including weight, drag, lift, thrust, and the lift of the wings. At some point during its trip the velocity of the plane is measured to be constant (which means its altitude is also constant). At this time, the net force on the plane:

A. is pointing upward
B. is pointing downward
C. is pointing forward
D. is pointing backward
E. is zero

Correct answer: E

Velocity is constant implies that there is no net force acting on it (The 1st Law). Therefore, all components of the net force are zero. Forces are balanced in all three dimensions.

The Four Fundamental Forces in Nature (so far)

- Types
  - Strong nuclear force (alpha decay, nuclear reactions)
  - Electromagnetic force (electricity, magnetism, chemistry, biology)
  - Weak nuclear force (beta decay, neutrino particles)
  - Gravity (apple falls, go upstairs, cars, space travel)

- Characteristics
  - All field forces: Action-at-a-distance
  - Listed in order of decreasing strength
  - Only gravity and electromagnetic forces are relevant in classical mechanics, which deals with motion of macroscopic objects.

Contact forces (usual pull and push): exerted between the surface molecules of the objects.

Mass or Inertia

- Mass (m) is the property of an object that measures how hard it is to change its velocity. (Thus the inertia)
  - As basic Units: [M] = kg

Importance of mass
- Braking car versus train
- Car versus bus going around curve
- Push on light or heavy object
- Mass determines how much force is exerted or is needed to achieve desired motion.
Newton’s Second Law
This law tells us how the motion of an object is affected when a force is applied.
In words: acceleration = (net force)/mass
The acceleration of an object is directly proportional to the net force acting on it, inversely proportional to its mass.
in symbols: \[
\ddot{a} = \frac{\vec{F}_{\text{net}}}{M} = \frac{\vec{F}_{\text{ext}}}{M}
\]
- **Most important law of mechanics:**
  - The 1st law is a special case, \( F = 0 \).
  - The constant of proportionality is called “mass”,
    This is the definition of mass: a constant property of that object, and independent of external influences.
- Force has SI units of \( [M][L/T^2] = \text{kg m/s}^2 = \text{N} \) (Newton)

Common examples:
(1). Force due to gravity: weight

\[
\vec{F}_g = m \vec{g}
\]
Near the earth’s surface, the magnitude of \( g \), the acceleration due to the earth’s gravitational field, is
\[
g = 9.81 \text{ N/kg} = 9.81 \text{ m/s}^2
\]
and is directed towards the earth’s center (the gravitational acceleration for free fall).
The acceleration due to gravity is the same for all objects.

Important concepts:
Weight: gravitational force on object: \( F = mg \).
Mass (or inertia): intrinsic property of object.

1 kg mass weighs \( \rightarrow 9.81 \text{ N on Earth} \)
(ref. 1 lb \( \approx 4.45 \text{ N} \))

If you stand on the moon, your weight is \( 1/6 \)th of the value that it has on earth, but your mass is the same as on earth (or in space, or anywhere).

(2). The Normal Force
When holding the bag above the table, the person must exert a force on the bag.
When the bag is placed on the table, the table supplies the force that holds the bag on it.
That force is perpendicular or normal to the surface of table.
Frictional force: against any motion/tendency.
(3). Springs

Hooke's Law: \( F = -kx \)
Where \( k \) is force constant, \( x \) is the displacement from the equilibrium point.

(4). Strings

A string has a fixed length. It can pull but not push.

The magnitude of the force that one segment of the string exerts on the adjacent segment is called tension (usually denoted by \( T \)).

Forces on gymnast:

\[
T_{\text{left}} + T_{\text{right}} = Mg
\]

Since gymnast is not accelerating, \( T_{\text{left}} + T_{\text{right}} = Mg \)

More on Tension

Tension is a force along the length of a medium.

Tension can be transmitted around corners if there is no friction in the pulleys, \( T \) remains the same.

Important technique: Free-Body Diagrams

Free-body diagrams are diagrams of the forces on an object.

First, isolate the object in question.
Then, identify the individual forces on it.

Forces acting on sled:
1. The gravitational force on the sled-rope
2. The contact force exerted by the ice on the runners. (Without friction, the contact force is directed normal to the ice.)
3. The contact force exerted by the dog on the rope.

(Since the sled remains on the ice, the y-components of the force sum to zero.)