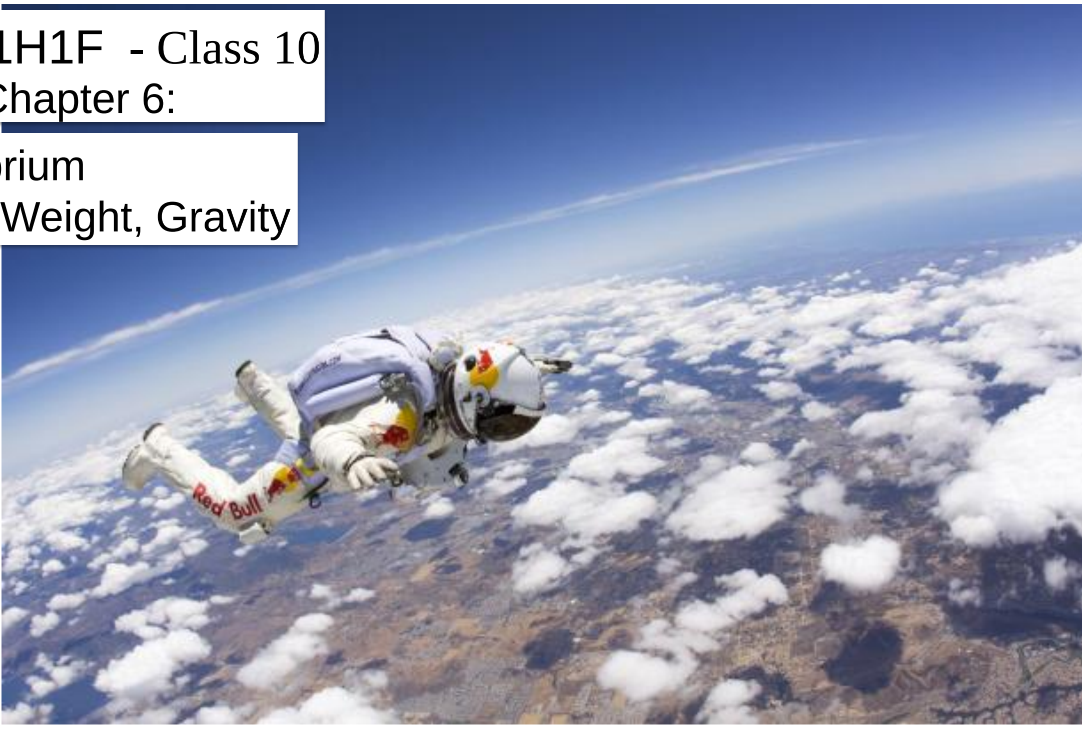
PHY131H1F - Class 10
Today, Chapter 6:

- Equilibrium
- Mass, Weight, Gravity



Clicker Question

Which of the following objects described below is in *dynamic equilibrium*?

A. A 100 kg barbell is held *at rest* over your head.

B. A steel beam is lifted upward at *constant speed* by a crane.

C. A baseball is flying through the air and *air resistance is negligible*.

D. A steel beam is being lowered into place. It is *slowing down*.

E. A box in the back of a truck doesn't slide *as the truck is slowing down*.

Last day I asked at the end of class:

- When astronauts are floating in a space station, are they really weightless?
- ANSWER: YES!
- Knight's definition of weight means the amount of force needed to support an object in your frame of reference.

WARNING

- Newton's Laws only apply in a "inertial reference frames". They are not valid if your reference frame is accelerating!
- An **inertial reference frame** is one that is **not accelerating.**

Clicker Question

- A car is driving at a steady speed on a straight and level road.

Quick quiz [1/4]: inside the car, is it…

A: Inertial Reference Frame

B: Not an inertial reference frame

Clicker Question

- A car is driving at a steady speed up a 10° incline.

Quick quiz [2/4]: inside the car, is it…

A: Inertial Reference Frame

B: Not an inertial reference frame

Clicker Question

- A car is speeding up after leaving a stop sign, on a straight and level road.

Quick quiz [3/4]: inside the car, is it…

A: Inertial Reference Frame

B: Not an inertial reference frame

Clicker Question

- A car is driving at a steady speed around a curve on a level road.

Quick quiz [4/4]: inside the car, is it…

A: Inertial Reference Frame

B: Not an inertial reference frame

Equilibrium $\boxed{\Sigma\vec{F} = 0}$

- An important problem solving technique is to identify when an object is in equilibrium.
- An object has zero acceleration if and only if the net force on it is zero.
- This is called “equilibrium”.
- If an object is in **vertical equilibrium** (ie it is confined to a stationary horizontal surface) then $(F_{\text{net}})_y = 0$. The sum of y-components of all forces = 0.
- If an object is in **horizontal equilibrium** (ie freefall) then $(F_{\text{net}})_x = 0$.

Gravity for the universe

It was Newton who first recognized that **gravity is an attractive, long-range force between *any* two objects.** Somewhat more loosely, gravity is a force that acts on mass. When two objects with masses m_1 and m_2 are separated by distance r, each object pulls on the other with a force given by Newton’s law of gravity, as follows:

$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{Gm_1m_2}{r^2} \qquad \text{(Newton's law of gravity)}$$

(Sometimes called “Newton’s 4$^{\text{th}}$ Law”, or “Newton’s Law of Universal Gravitation”)

Gravity Example

A mass, *m*, rests on the surface a giant spherical rock which is floating in space.
The giant rock has a mass of 6×10^{24} kg and a radius of 6400 km.

(a) What is the force of gravity on the mass due to the giant rock?
(b) Can you think of a good name for this giant rock?

Gravity for Earthlings

If you happen to live on the surface of a large planet with radius R and mass M, you can write the gravitational force more simply as

$$\vec{F}_G = (mg, \text{straight down}) \qquad \text{(gravitational force)}$$

where the quantity g is defined to be:

$$g = \frac{GM}{R^2}$$

At sea level, $g = 9.83\ \text{m/s}^2$.
At 39 km altitude, $g = 9.71\ \text{m/s}^2$.

Gravity: $F_G = mg$ is just a short form!

$$F_{1\text{ on }2} = F_{2\text{ on }1} = \frac{Gm_1m_2}{r^2}$$

and

$$\vec{F}_G = (mg\text{, straight down})$$

are the same equation, with different notation!

The only difference is that in the second equation we have assumed that $m_2 = M$ (mass of the earth) and $r \approx R$ (radius of the earth).

Weight ≠ Weight ??!?

- Physicists do not all agree on the definition of the word “weight”!
- Sometimes “weight” means the exact same thing as “force of gravity”. That is ***not*** how Randall Knight uses the word.
- In Knight, “weight” means the magnitude of the *upward* force being used to support an object.
- **If the object is at rest** or moving at a constant velocity relative to the earth, then the object is in equilibrium. The upward supporting force exactly balances the downward gravitational force, so that weight = mg.

Clicker Question

- When I stand on a scale in my bathroom it reads 185 pounds. 2.2 pounds = 9.8 Newtons, so this means the upward force on my feet when I am standing still is 185 lbs (9.8 N / 2.2 lbs) = 824 N.
- If I ride an elevator which is accelerating upward at 1.5 m/s^2, what is the upward force on my feet?
- With no calculations, take a wild guess from this list:

A. 824 N
B. 950 N
C. 698 N
D. 0 N
E. –824 N

Knight's Definition of weight Eq. 6.10, page 147:

The **weight** of an object is the reading of a calibrated spring scale on which the object is stationary. Weight is the result of weighing. The weight of an object with vertical acceleration a_y is

$$w = mg\left(1 + \frac{a_y}{g}\right)$$

Clicker Question

Spring scale on an elevator

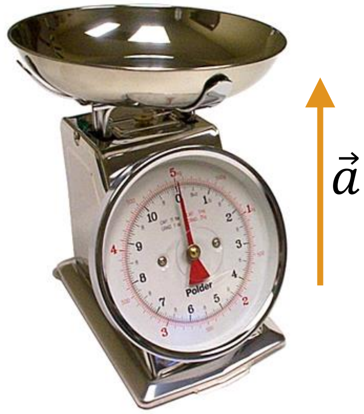
You are attempting to pour out 1.0 kg of flour, using a kitchen scale on an elevator which is accelerating upward at 1.5 m/s^2.

The amount of flour you pour will be

A. too much.

B. too little.

C. the correct amount.



Clicker Question

Pan balance on an elevator

You are attempting to pour out 100 g of salt, using a pan balance on an elevator which is accelerating upward at 1.5 m/s^2. Will the amount of salt you pour be

A. Too much

B. Too little

C. The correct amount

Self-adjusting forces

- Gravity, F_G, has an equation for it which predicts the correct magnitude (it's always mg here on Earth).
- Normal force, Tension and Static friction are all self-adjusting forces: ***there is no equation for these!!***
- **Normal force** is whatever is needed to keep the object from crashing through the surface.
- **Tension** is whatever is needed to keep the string or rope from breaking.
- **Static friction** is whatever is needed to keep the object from slipping along the surface.
- In all these cases, you must draw a free-body diagram and figure out by using equilibrium and Newton's 2nd law what the needed force is.

Getting the piano on the truck

- A piano has a mass of 225 kg.

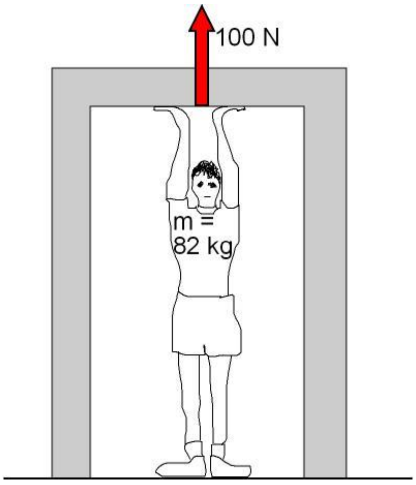
1. What force is required to push the piano upwards at a constant velocity as you lift it into the back of a truck?

- A piano has a mass of 225 kg.

2. What force is required to push the piano up a frictionless ramp at a constant velocity into the truck? Assume the ramp is 3.00 m long and the floor of the truck is 1.00 m high?

Clicker Question

Bob stands under a low concrete arch, and presses upwards on it with a force of 100 N. Bob's mass is 82 kg. He is in equilibrium. What is the total **normal force** of the ground on Bob? (Note that 82 × 9.8 = 800.)



A. 800 N, upward
B. 800 N, downward
C. 900 N, upward
D. 700 N, upward
E. 900 N, downward

Before Class 11 next Wednesday

- Please finish reading Chapter 6
- Problem Set 4 is due Sunday night.
- Please read the rest of Knight **Chapter 6.**
- Something to think about:

Does friction always slow things down? Can friction ever speed things up?

Happy Thanksgiving!