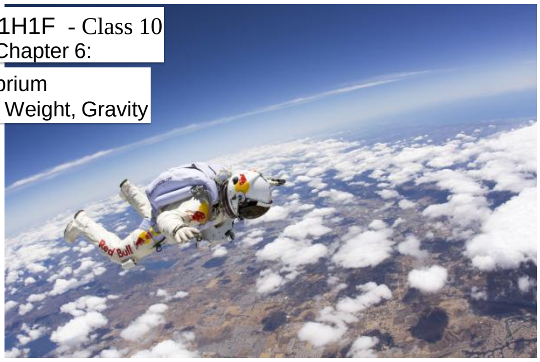
PHY131H1F - Class 10

Today, Chapter 6:

- Equilibrium
- Mass, Weight, Gravity



Clicker Question 1

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.

Preparation for Practicals today, tomorrow and Friday:

- Take a ride on the Burton Tower elevators!
- All 4 elevators in the 14-storey tower of McLennan Physical Labs are equipped with a hanging spring-scale.
- It measures the upward force necessary to support a 750 g mass. (a.k.a. "weight")
- You may find that the measured weight of this object changes as you accelerate – check it out!

Last-night's Midterm Test

- Thanks for writing the test last night
- If you missed it, please bring medical documentation to April Seeley in MP129
- I have posted solutions on the course web-site under "Lectures – Harlow"
- We will get it marked as soon as possible – probably 1 or 2 weeks, then return it to you in Practicals

Survey

Last-night's Midterm Test

- Often students find that preparing an aid-sheet is a good way to study **before** a test.
- How useful was your aid-sheet to you **during** the midterm test?

A. Very useful (I referred to it for more than half the questions)

B. Useful

C. A little bit useful (I may have checked it once or twice)

D. Not useful

E. Honestly, I did not need the aid-sheet at all during the test!

- 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 2

- 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 3

- 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 4

- 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 5

- 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

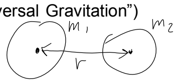
It was Newton who first recognized that **gravity is an attractive, long-range force between *any* two objects.** Somewhat more loosely, gravity is a force that acts on mass. When two objects with masses m_1 and m_2 are separated by distance r, each object pulls on the other with a force given by Newton's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

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

(Sometimes called "Newton's 4th Law", or "Newton's Law of Universal Gravitation")

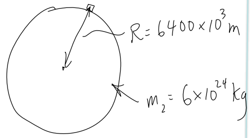
$G = 6.67\times10^{-11}\ \frac{N\cdot m^2}{kg^2}$

r = centre-to-centre distance of m_1 & m_2.



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.
What is the force of gravity on the mass due to the giant rock? $m_1 = m$



$F_g = \frac{G m_1 m_2}{R^2}$

$= \frac{6.67\times10^{-11}(m)\,6\times10^{24}}{(6400\times10^3)^2}$

$F_g = 9.8\ m$

Units of 9.8

$\left[\frac{N\cdot m^2}{kg^2}\right]\frac{kg}{m^2} = \left[\frac{N}{kg}\right]$

$1\ N = \frac{kg\,m}{s^2}$ $\quad \frac{N}{kg} = \boxed{\frac{m}{s^2}}$

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

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

where the quantity g is defined to be:

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

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

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 ??!?

- Physics textbooks and physics teachers 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. (I will follow Knight's definitions.)
- 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 6

- 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/s², 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

fbd. of Harlow

When $a = 0$, Scale reads n.

$(F_{net})_y = 0 = n - mg$

$n = mg = 824\ N$

$\vec{a} = 1.5\ m/s^2$, up

$a_y = +1.5\ m/s^2$

$(F_{net})_y = ma_y = n - mg$

Solve for n: $n = ma_y + mg$

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

$n = 824\left(1 + \frac{1.5}{9.8}\right) = \boxed{950\ N}$

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

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

Note, in freefall $a_y = -g$

$$w = mg\left(1 + \frac{-g}{g}\right) = mg(1-1) = 0$$

weightless!

Clicker Question 7

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 8

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?

$\vec{a} = 0 \Rightarrow \vec{F}_{Net} = 0$

$(F_{Net})_y = 0 = F_p - mg$

$F_p = mg = (225)(9.8)$

$\boxed{F_p = 2200\text{ N}}$

- 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?

Getting the piano on the truck

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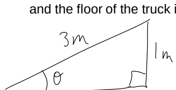
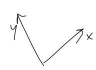


$\vec{a} = 0$

$F_{Net} = 0$

Define:



	x	y
$\vec{n}$	0	n
$\vec{F}_p$	F_p	0
$\vec{F}_g = mg$	$-mg\sin\theta$	$-mg\cos\theta$
$F_{Net} = 0$		

$(F_{Net})_y = n - mg\cos\theta = 0$

$n = mg\cos\theta$

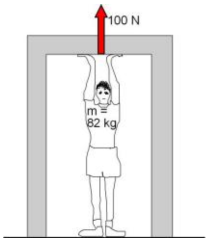
$(F_{Net})_x = F_p - mg\sin\theta = 0$

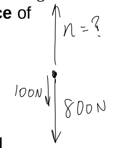
$F_p = mg\sin\theta = (225)(9.8)\left(\frac{1}{3}\right)$

$F_p = 735$ N.

Clicker Question 9

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 $82 \times 9.8 = 800$.)





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

$(F_{net})_y = 0 = n - 800 - 100$

Before Class 11 next Wednesday

- Please finish reading Chapter 6
- Problem Set 4 is due Sunday night.
- Take a ride on the Burton Tower elevators, do prep-work for Mechanics Module 3 Activity 2.
- 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!