

HK IPhO Training class

(mechanics)

T. K. Ng, HKUST

Introduction: Newton's Law of motion

- 1) *An object remains in its state of rest or uniform motion (moving with uniform velocity) if there is no net force acting on it.*
- 2) *$F=ma$*
- 3) *When a body A exert a force F on body B, there is a reaction force $= -F$ acting on A itself.*

Newton's Law of motion

*Classical Mechanics is built on
Newton's three Law's of motion:*

*Before we go into more difficult
problems/examples, we first review
the meanings of the three laws.*

Recall Newton's First Law:

An object remains in its state of rest or uniform motion (moving with uniform velocity) in a straight line if there is no net force acting on it.

$$\mathbf{F} = 0$$

The first part of the first law is probably easy to accept. However, **the second part is not so trivial.**



How about the following?

Question: At pre-Newton's time people believed that $\mathbf{F} = m\mathbf{v}$ (Force is proportional to velocity instead of proportional to acceleration). Can you find some simple demonstrations/examples showing that this cannot be correct?

Exercise: Find daily life examples that seems to support $F = m.v$.

Example (a):

A running bus at uniform velocity (speed) still needs to burn gasoline.

Friction force exist between wheel and ground.



Another example that seems to support $F = m \cdot v$.

Example (b):

You felt force if a car running at uniform velocity hits you.

When the bus hits you, its velocity changes!

Exercise: Find daily life examples that support Newton's first law.

- Example:
- Suppose you are inside a room in a big cruise boat. Can you detect the boat's movement in the room if the boat is moving very steady?



“Non-trivial” example that seems to violate Newton’s first law.

An astronaut at an orbit around the earth (although the astronaut is accelerating, he/she does not feel force!).



It is trickier. It is related to the problem of so-called inertial reference frame which we shall discuss later when we are a bit more familiar with Newton’s Law.

Newton's Second Law:

Newton's second law is usually summarized in terms of a simple equation

$$\mathbf{F} = m\mathbf{a}$$

Where

\mathbf{F} is net force acting on an object.

m is the mass of the object, and

\mathbf{a} is the acceleration of the object under the net force.

Newton's law tells us in a **mathematically very precise way** what is the effect of a (net) force acting on any given (point) object.

Examples of Newton's Second Law:



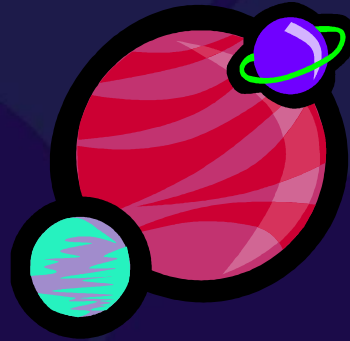
straight line motion (moving bus)

Examples of Newton's Second Law:



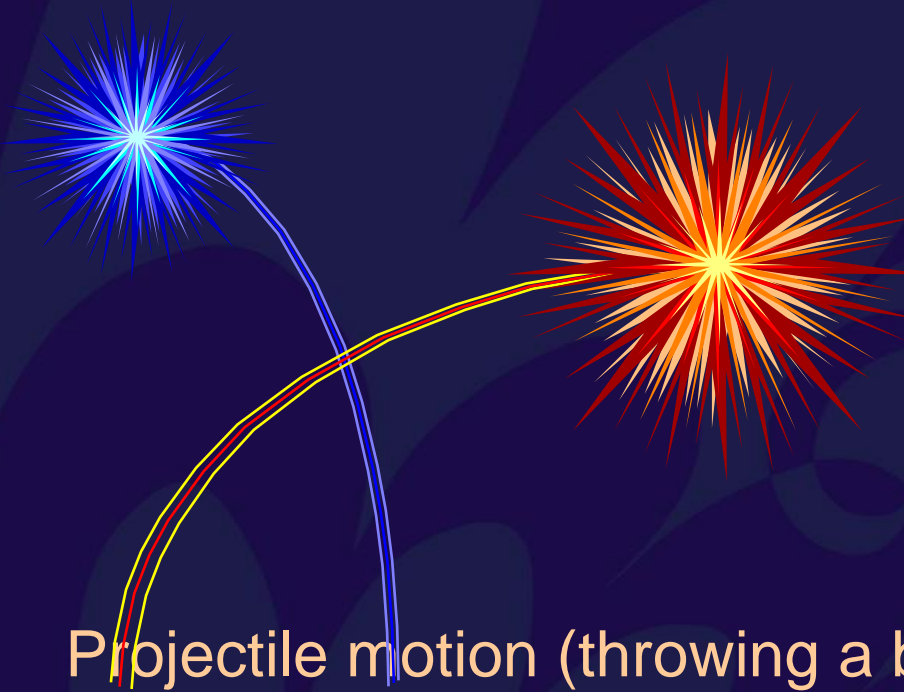
harmonic oscillator

Examples of Newton's Second Law:



circular motion (car turning in circle, planets around sun)

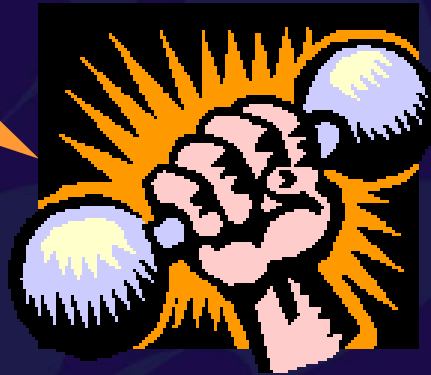
Examples of Newton's Second Law:



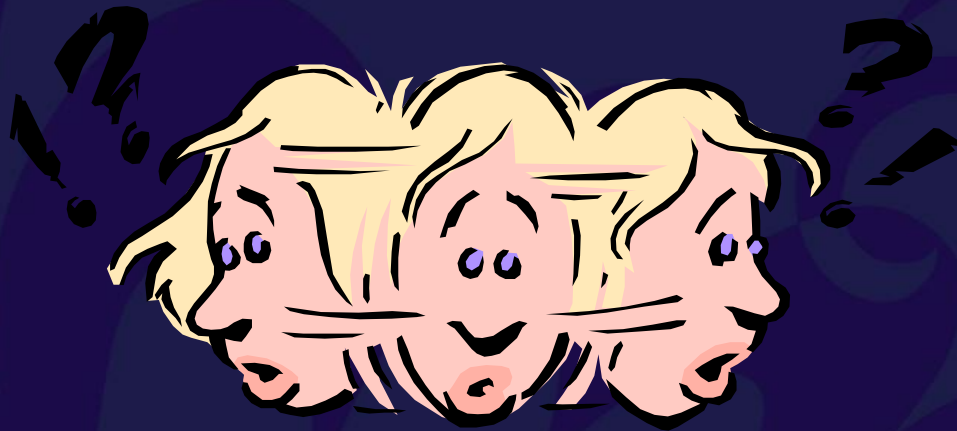
Projectile motion (throwing a ball across space)

Question: How is force defined?

$F = ma?$
Y/N??



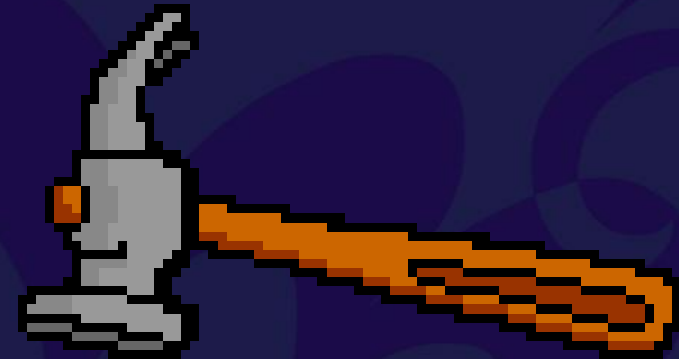
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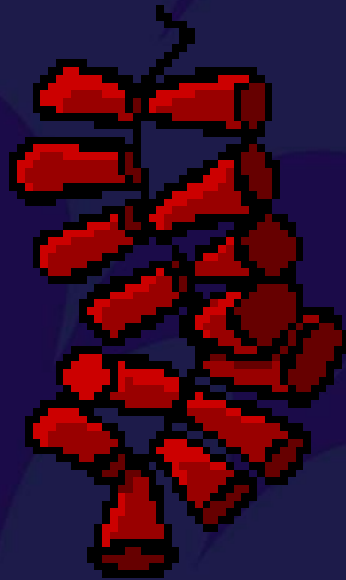
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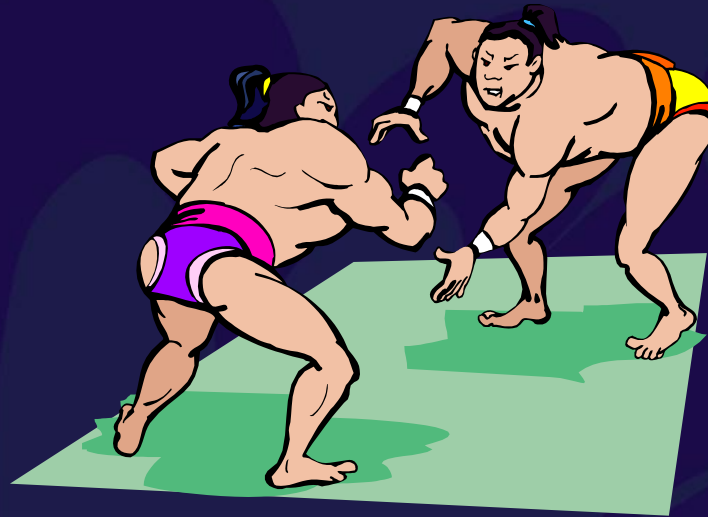


To be concrete let's first consider the
“pushing *force*” from a human being
- the force felt by the object you
“push”.



Exercise:

Design a way of comparing the “pushing *force*” of human beings.



Supposed you have succeeded in finding a way to measure “pushing force”. Now, let’s imagine “pulling” instead of “pushing”

Can you **decide a method** to compare “pulling” force?

Can you **compare** pushing and pulling forces with your methods?

What did you assume in order to compare pushing and pulling force?

(If we don’t know anything about Newton’s Law.)



To make it possible to compare forces of different origins and natures we have to make an important assumption.

Assumption (1): The sum of all forces acting on an object must be zero when the object is motionless.



When the object is stationary, the sum of pushing and pulling force on the body must be zero.

$$F_{\text{push}} + F_{\text{pull}} = 0$$

$$F_{\text{push}} = -F_{\text{pull}}$$

Since we have already established **methods** to compare magnitudes of **pushing** and **pulling** forces separately, we can now **compare** **pulling** and **pushing** forces with this criterion.



It is what happens when you are on the scale.



You are “pulled” by the gravitational force between you and the earth.

You are “pushed” up by the spring inside the scale.

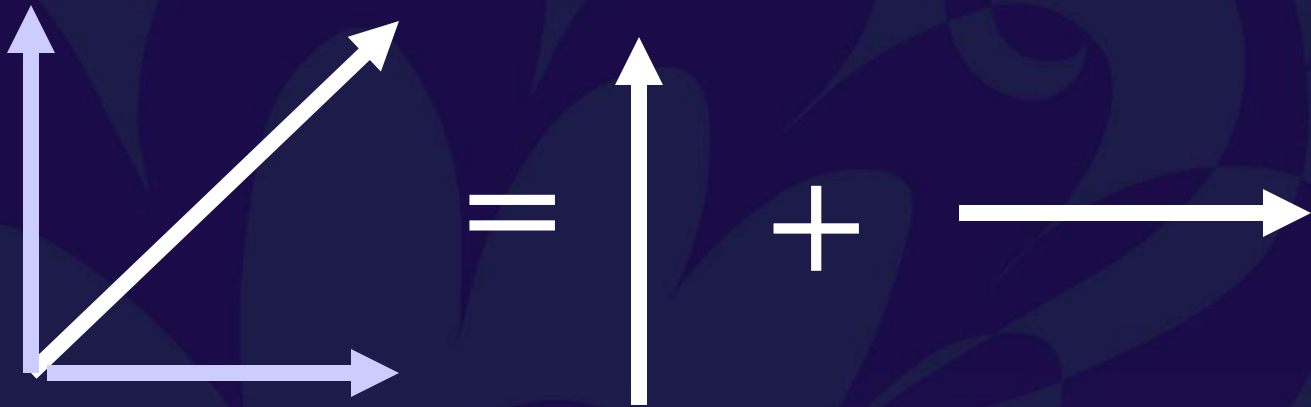
When you are not moving as you should behave on a scale, the two forces balance. (The deformation of spring indicates your weight on earth.)

Notice that force has both
magnitude and *direction*.



Force is a *vector*.

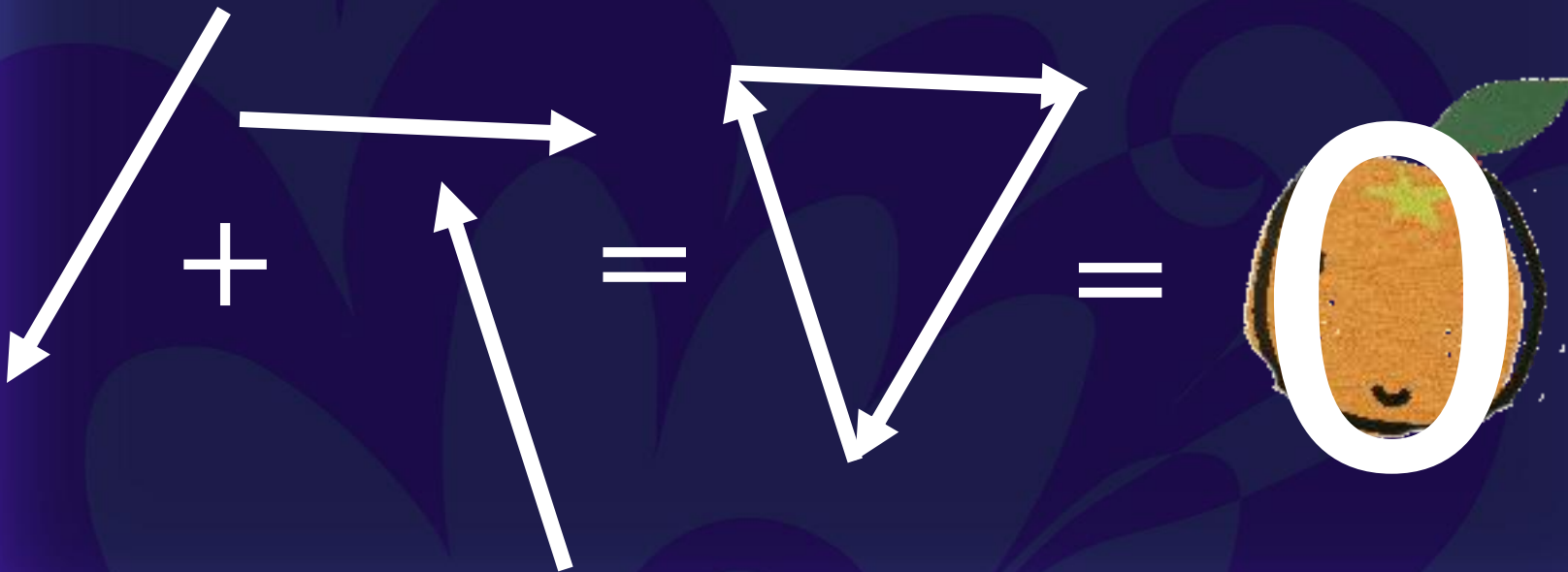
Property 1: Any vector in an N -dimensional space can be decomposed into N -orthogonal components ($N=3$ in our physical space). There are infinite number of ways to assign these N -components. A unique way of writing down its N -components is specified once we specify a coordinate system.



Property 2: Two vectors are equal when **all** its components are equal. A vector is equal to **zero** when all its components are equal to **zero**.

Important consequence of nature of vector:

We can have three (or more) vectors of different magnitudes and along different directions and they may add up to **zero**!



Some examples of forces

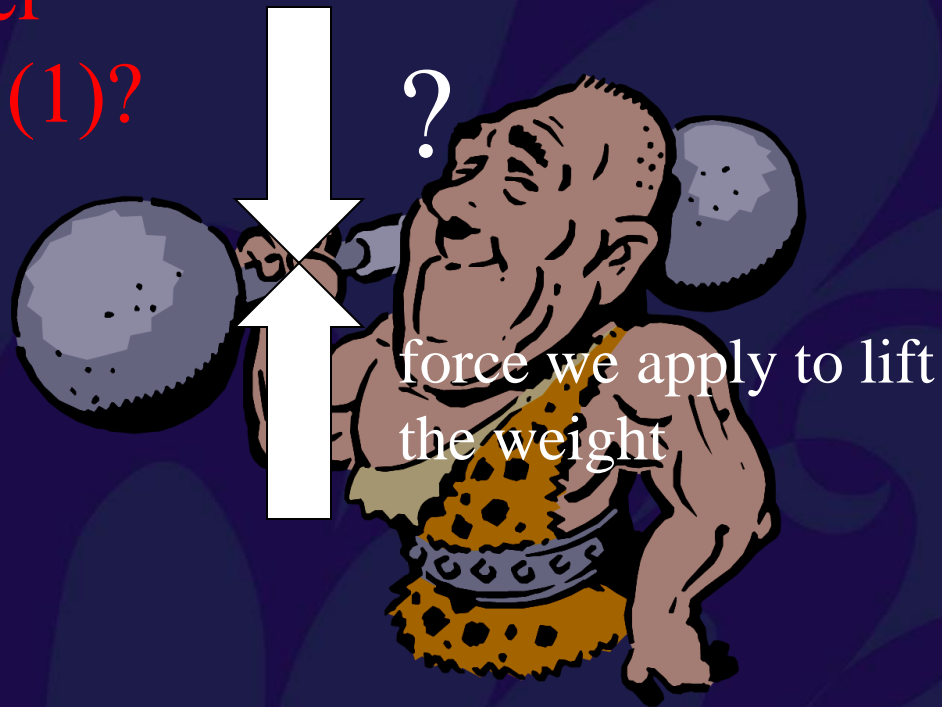
What is weight?

Remember
Assumption (1)?



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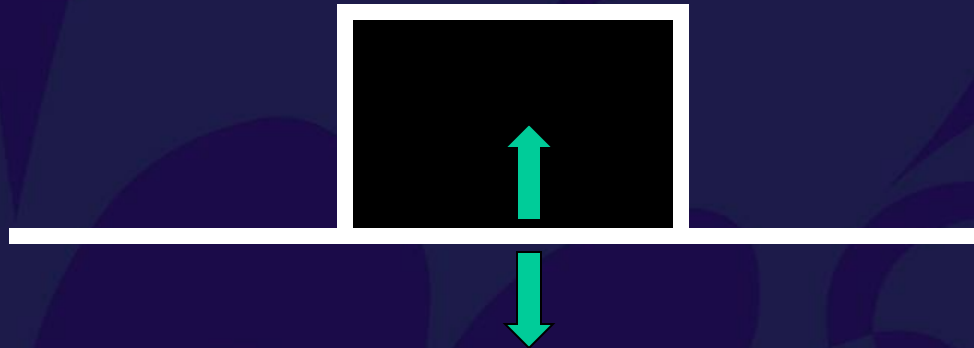


Weight & Gravity



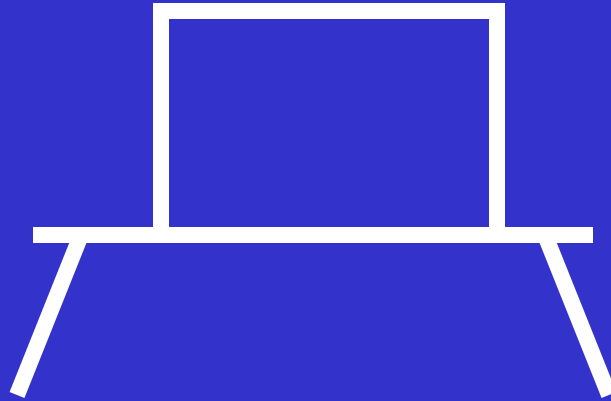
Since the object is **motionless**, the net force acting on the object must be **zero**. Therefore, there must be a downward force which balances our applied lifting force. This is the gravitational force.

Normal force acting on a resting object

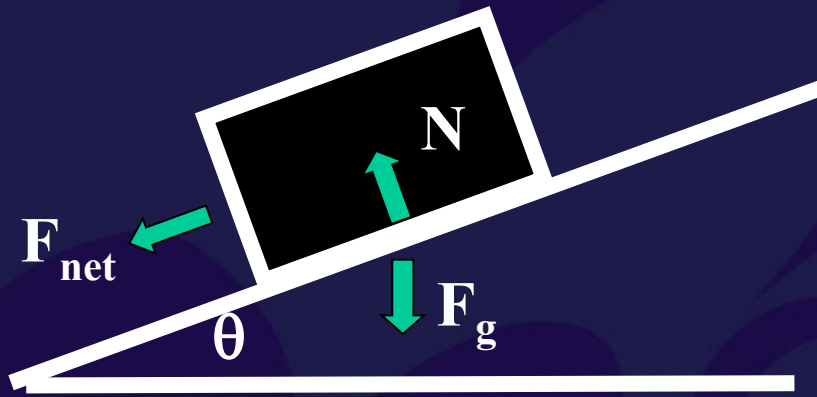


Since the object is **motionless**, the net force acting on the object must be **zero**. Therefore, there must be a upward force from the ground which balances the gravitational force. This is usually called *normal force*.

Exercise: How about the following? What are the direction of forces acting on the “legs” of the chair? (Notice the use of “vector” addition)



Normal force on an inclined plane



Gravitational force: pointing down

Motion of object is along inclined plane.

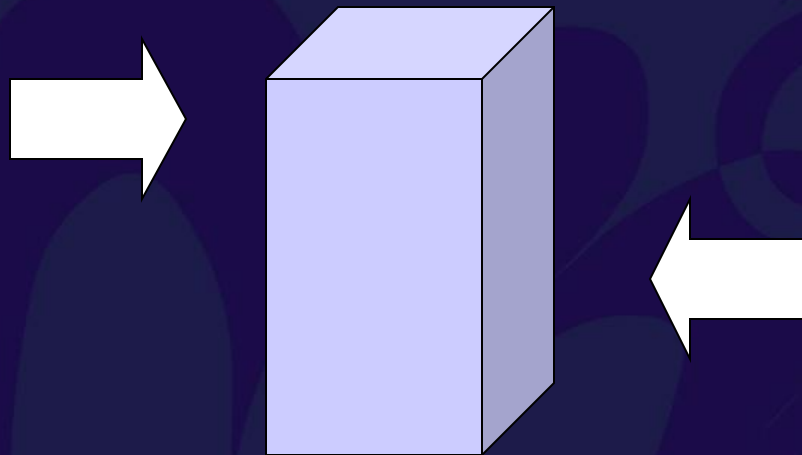
Net force on object F_{net} is *not* Pointing down.

$$N = F_g \cos \theta, F_{\text{net}} = F_g \sin \theta$$

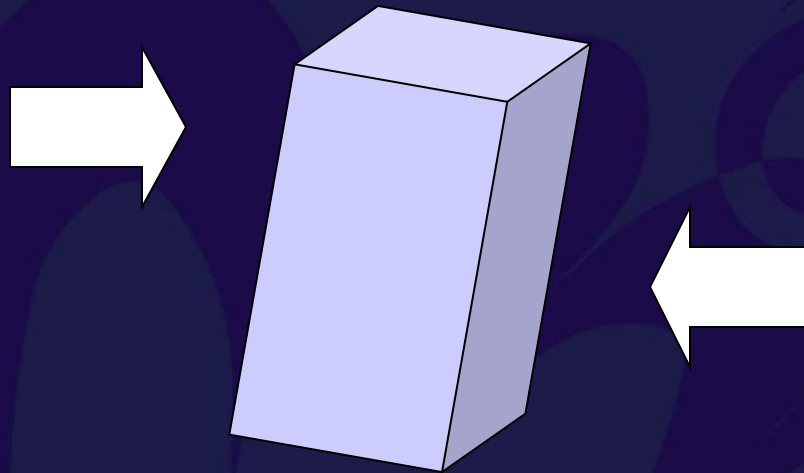
Caution:

Forces acting on *different* points of an
extended object

For an extended object (like an human being), we can apply equal and opposite force on different parts of an object. What would happen then?

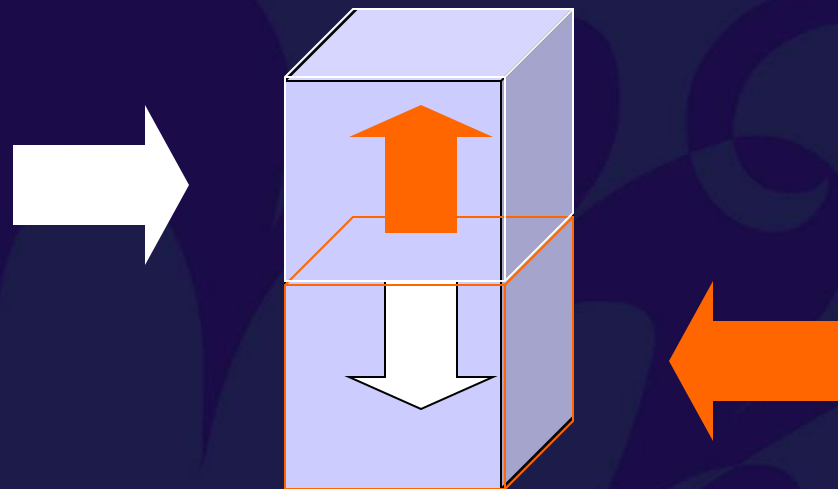


Experience told us that the above object will *turnover* (rotate). So, when we apply Newton's Law saying that an object is motionless (or travel with uniform velocity) when total applied force is zero, we have to be careful.



For an extended object, **this** is correct only if the total force acting on *every part of the object* is zero.

Another way is to consider the extended object as build up by two parts hold together by a third force, you can see why the object has to turn then.



What is force?

Have we answered the question?



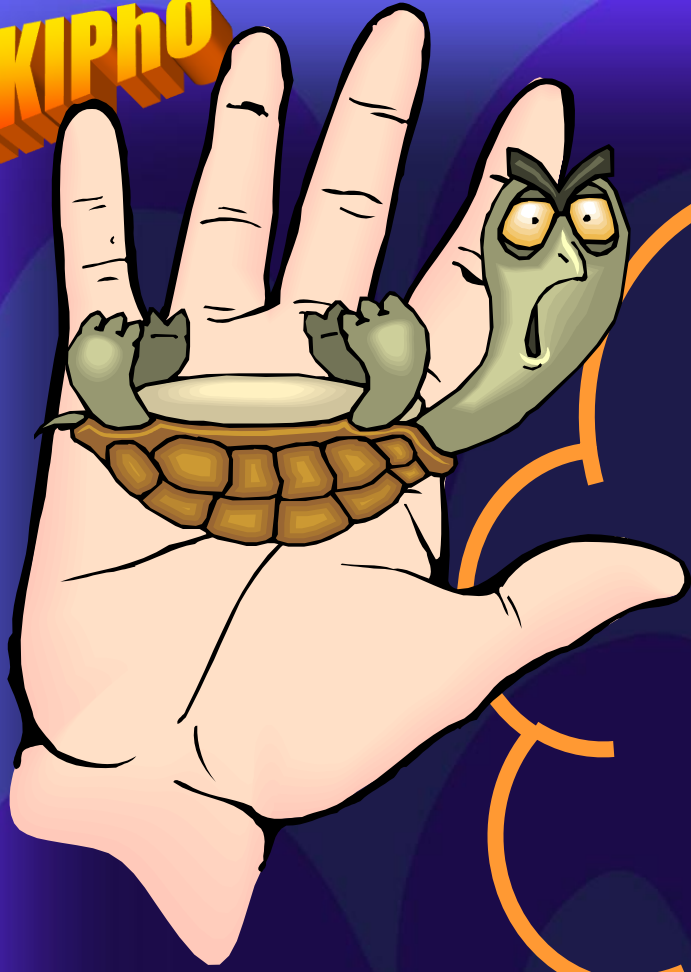
Oh! I forget
to ask.



You may be rather dissatisfied with this chapter if you want to know what is the true nature of force beyond what we feel.

What is happening
in nature when we
feel some force is
acting on us?





Is the space-time
around our finger
got twisted when
we try to lift up
something?

How is force transmitted from one object to another?





All these questions are **not**
answered in this chapter.



What you have seen in this chapter is how science works in **real life**. Scientists are no cleverer than you or me, and they cannot answer the above questions without more information.

When scientists start to solve a problem, they have to start with the **simplest** problem first



- some simple organization work of **how to measure/compare** different forces in our case.

We see that additional insights come up if the organization work is well done



- such as the necessary existence of normal force, friction force and others.

This is how science
progresses most of the time,



not by sudden discovery of
great hidden mysteries,

but by recognition of *the deep
meaning of simple things in our
daily life.*

Newton's third Law: Force from A on B = - Force from B and A

$$\mathbf{F}_{ab} = -\mathbf{F}_{ba}$$

Newton's third law did not tell us about again the true nature of force, except that no matter what forces are, they must satisfy a constraint – they always come in equal and opposite pairs

- But Why?

Newton's third Law: Force from A on B = - Force from B and A

$$\mathbf{F}_{ab} = -\mathbf{F}_{ba}$$

Newton's third law leads to a number of fundamental conservation laws: *conservation of momentum, angular momentum, energy*. We shall see these later.

Newton's Law & simple applications

Newton's Second Law

$$\vec{F} = m\vec{a};$$

$$\text{or } F_{\alpha} = m \frac{d^2 x_{\alpha}}{dt^2}; \quad (\alpha = x, y, z)$$

$$F=0 \Rightarrow a=0$$

Or $v = \text{constant}$ (Newton's first Law)

Newton's Law & simple applications

Example: one dimensional motion

$$F = m\ddot{x}$$

F = constant

$$\Rightarrow x(t) = x_0 + v_0 t + \frac{1}{2} \left(\frac{F}{m} \right) t^2$$

Notice, we need two initial constants to specify the solution

Newton's Law & simple applications

Example: gravitational force

$$F = -mg$$

$$\Rightarrow z(t) = z_0 + v_0 t - \frac{1}{2} g t^2$$

We shall see more examples later.

End of lecture I

