PH101
Lecture 7

14.08.14

Limitations of Newtonian Mechanics

- Breaks down at speeds comparable to *c*
- Fails for systems of atomic dimensions where quantum effects are significant
- Why?
- Because of inadequacies in classical concepts of space and time and nature of measurement
- We can not disregard classical physics in favour of modern physics!
- Newtonian mechanics is exceptionally useful in several areas of physics though limited applicability in certain other areas
- e.g. to predict occurrences of eclipses centuries in advance!
- But completely fails in predicting motion of electrons in atoms
- It is an essential tool for explaining several phenomena that we observe/ come across in nature

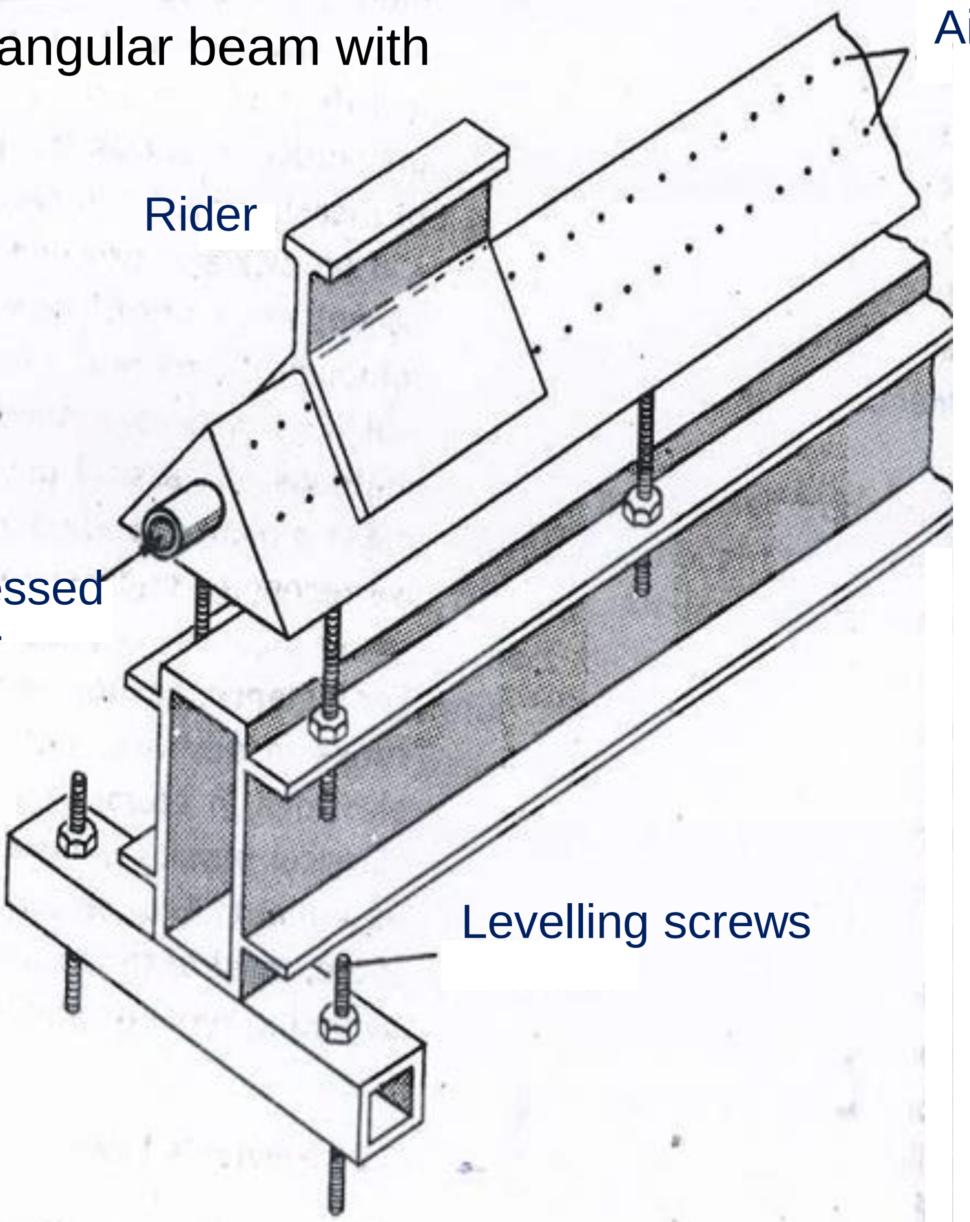
Imp to realize which parts of Newton's laws are based on experiment and parts which are matter of definitions

Motions in our every day surroundings are complicated by influence of forces like gravity and frictions

Best would be to carry out experiments related to mechanics in outer space

Alternative: *Linear air track* which approximates ideal conditions in 1D

- About 2m long hollow triangular beam with rider resting on it
- Pierced by several small holes which emit gentle streams of air
- When air is turned on the rider floats on a thin cushion of air
- Viscosity of air is 5000 times less than that of a thin film of oil
- Rider behaves as if isolated free from influence of gravity, friction or any other detectable forces



Linear air track approximating ideal isolated system in 1D

Suppose we place the rider on the track and carefully release it from rest

It will stay at rest unless a draft or some such external agency hits it

Give it a slight push, and let it move freely.

It keeps moving evenly neither gaining nor losing speed contrary to everyday experience

If we turn off the air, it will come to a halt due to sliding friction

Motion has meaning only w.r.t a particular coordinate system

In a coordinate system moving uniformly w.r.t the track, the undisturbed rider moves with a constant velocity; this is example of an *inertial* system

It is always possible to find a coordinate system w.r.t which isolated bodies move *uniformly*

Newton’s first law is the assertion that inertial systems exist

Newton’s first law is part definition and part experimental fact

Existence of inertial systems

Isolated bodies move uniformly in an inertial system

The way inertial system is defined

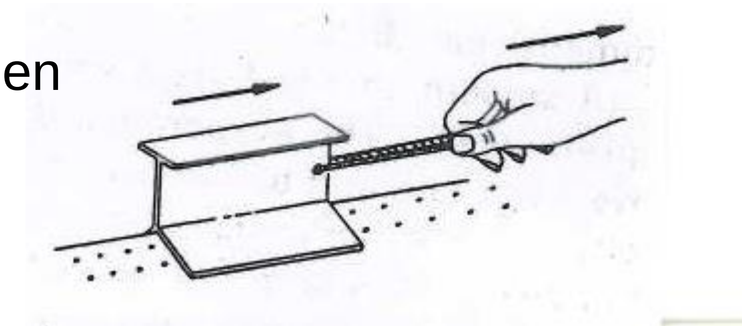
The inertial systems exist is a statement about the physical world

Q’s: What is meant by an isolated system

Consider the case when the rider is not isolated any longer

It is being pulled by a rubber band

Unless pulled hard enough nothing will happen



Its velocity will increase uniformly with time i.e. with const. acceleration if we move our hand ahead of the rider

If we repeat the expt. with another much heavier rider, const. acceleration this time would be different

Even though we carry the expt. in an identical manner, acceleration depends on some property of the rider!

We call *mass*, which we define in the following way:

If we arbitrarily assume mass of rider 1 as m_1, mass of the 2nd body is defined through

$$m_2 = \frac{a_1}{a_2} m_1$$

Mass is an inherent property of a body independent of the source of acceleration. It is an *operational* definition

If the expt is repeated even with springs/magnets , the above ratio of masses or acceleration will be same independent of the source of acceleration

$\Rightarrow$ an inherent property of the body

Our definition of *mass* holds not only for everyday objects on earth but also for motion of celestial objects on an enormously larger scale as well to a high degree

In the just discussed experiment, the rubber band was used to *apply* a force to the test mass although <u>not</u> stating what a force is

Under the influence of force the test mass acquires an acceleration

Under the influence of a pair of stretching rubber bands side by side, the test mass acquires an acceleration, 2*a*

If applied in opposite directions, acceleration of the test mass is 0 $\Rightarrow$ effects of the two rubber bands linearly add for the motion in a straight line

A force scale: unit force as the force which produces unit *a* when applied to a unit mass

$\Rightarrow$ *F* units of force wld accelerate unit mass by *F* units of acceleration

$\Rightarrow$ *F* X (*1/m*) units of acceleration in mass *m*

$\Rightarrow$

$$a = \frac{F}{m} \qquad \Rightarrow F = m\,a$$

Newton
1 N =
1 kg.m/s^2

kg

m/s^2

Since **a** is a vector, **F** wld also be a vector because *m* is a scalar

What about its direction?

Forces obey *Principle of superposition*

a produced by several forces equals <u>vector sum</u> of *a'*s produced by each of these

Total force on a body of mass *m*:

$$\vec{F} = \sum \vec{F}_i = \sum m\vec{a}_i = m\sum \vec{a}_i = m\vec{a}$$

This is Newton's 2nd law

Imp: Force is not a mere definition!

If the rider starts accelerating?

It arises from *interaction* between systems

Which is physically significant & responsible for force

Isolation implies elimination of interactions

Is it feasible?

Examples: Coulomb or Gravitational forces

$$\propto \frac{1}{r^2}$$

Force between separated atoms $\propto \frac{1}{r^7}$

Force is necessarily the result of an interaction

Explicit in Newton's 3rd law

Forces always appear in pairs

If *b* exerts $\mathbf{F}_a$ on body *a*, there must be a $\mathbf{F}_b$

$$\mathbf{F}_b = -\mathbf{F}_a$$

3rd law leads to conservation of momentum

Difficulties in Newton's law:

1. *Mass* scale is not const. at *v* is comparable to *c*

$$m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$$

m_0: rest mass

In everyday velocities, even for vel. of an earth orbiting spacecraft

$$v << c;\ v/c \approx 3 \times 10^{-5}$$

m and m_0 differ by a few parts in 10^{10}

2. It refers to point masses. If size of the body is small compared to interaction distance, it offers no problem. e.g. sun and earth

Even for large bodies, Newton's laws can be generalized

3. Newton's laws poorly suited for continuous systems

e.g. fluids

Both mass and force are continuously distributed

Subject of Fluid Mechanics

Fundamental standards

Length, time and mass

SI units:

Length: 1 meter (m)

Mass: 1 kilogram (kg)

Time: 1 second (s)

Acceleration: $1 m/s^2$

Force: 1 newton (N) = $1 kg.m/s^2$

Everyday forces of Physics

Example, design of an accelerator

Prediction of motion from known forces

Converse is equally imp in Physics

Newton’s deduction of gravitation law from Kepler’s laws

Interaction between elementary particles from high energy experiments

Mechanics deals with how a system behaves under applied forces

If every pair of particles has its own interaction!

Nature is kinder

Only four fundamental interactions: $\overbrace{\text{gravity, em}}^{\text{Long range}}$, $\underbrace{\text{weak and strong}}_{\text{Short range} \sim 10^{-15}\text{ m}}$ interactions

Gravitational forces is always attractive

Electrical forces can be either attractive or repulsive

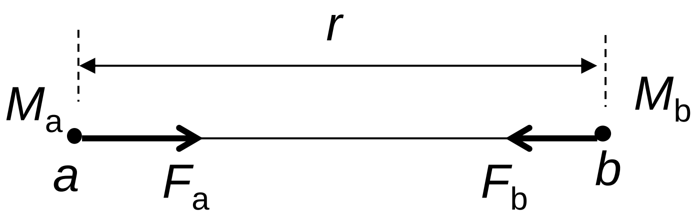
For large systems it may cancel out to a large degree

Hence Gravitational forces dominate the cosmic scale of the universe

Electrical forces are responsible for the structure of atoms, molecules and matter

Also for existence of light!

Gravity, weight and gravitational field



$$\left|F_b\right| = \frac{GM_a M_b}{r^2}$$

It is central