Physics 131 Lecture 4

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Forces and Newton's Laws

Revision Forces

- In this and following chapters we study the forces that are responsible for the (accelerated) motion of objects

- The study of the origin of motion and motion variations is called Dynamics (Dyna = force). The question we ask ourselves here is **why**, what is the **cause** of the motion…

- That is truly the gist of Physics: what causes all the structure we see around us…?

- As we saw before, from the **motion** we can derive the acceleration, which (by Newton's 2nd Law) gives us the force responsible!

  Thus, from the motion we can find out about the interaction, i.e. study the force as function of time, distance, charge, and many other variables…

Types of Forces

- There are many types of forces:
  - **Contact Forces**
    Examples:
    - sliding friction and static friction:
      $\mathbf{F}_f$ acts parallel to the sliding surfaces in a direction that opposes the sliding motion
    - friction in fluids and gases: $\mathbf{F}_f$ acts mostly i opposition to the motion, and depends on detail on the shape of the object (e.g. airplane wing)
    - Tension force: the force exerted by a compressed or stretched spring, an elastic band, or a simple rope.
      Normal forces: elastic or inelastic contact forces; e.g. force due to (small) compressio of table onto my book…
  - **Long-Distance Forces**
    No contact is necessary; examples:
    - Gravity (PHY131)
    - Electromagnetism (PHY132)
    - The "Weak" force (responsible for radioactivity)
    - The "Strong" or Nuclear force (which keep the nucleus together)

Example

- 1st Law:
  Objects that undergo zero net force, will move with constant velocity
  - The net force $\mathbf{F}_{Net}$ is the **vector sum** of all forces acting on the object:

$$\mathbf{F}_{Net} \equiv \sum \mathbf{F}_i \equiv \mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3 + \ldots$$

    where the vector forces $\mathbf{F}_1$, $\mathbf{F}_2$, $\mathbf{F}_3$ are all acting ON THE OBJECT in question!
  - velocity is a vector:
    i.e. as long as no net force acts on the object it will continue to move with constant **speed and direction** forever…

    If the body was at rest initially, it will stay at rest forever…

    Dynamical Equilibrium!
  - Constant velocity in time: i.e. **zero acceleration!**
- **1st Law:** $\mathbf{F}_{Net} = 0 \Leftrightarrow \mathbf{a}=0 \Leftrightarrow \mathbf{v}$ is constant

Newton's 1st law-Examples

Examples:

- in the complete absence of friction forces, a (smooth) ice hockey puck would continue to slide on the ice forever, without changing speed or direction!
  The more friction-less the interface between puck and ice, the better that is true in real life…
- clearly there are forces acting on the puck: gravity (downwards)
  and the normal force by the ice (or thin layer of water on it) pushing back up on the puck, such that the NET VERTICAL FORCE is zero…
- if the HORIZONTAL FRICTION FORCE is zero as well, the puck would keep sliding forever (or until it hits the goalie)…

Reference Frame

Note, that quantities like position $\mathbf{r}(t)$, and its derivatives velocity and acceleration, are measured with respect to a set of coordinate axes, i.e. in a so-called "**Reference Frame**"

- This Reference Frame is typically chosen for convenience:
  - it can be the frame of the Physics Lecture hall, with proper choice of origin and axis directions…
  - it can be the frame of an automobile or the LIRR, if we are doing physics in the car or the train…
  - it can be the galaxy with axis directions defined by a few very far way stars, for the study of planet motion in the solar system…

Reference Frames

Note, that the first law is NOT VALID in al "reference frames", only in so-called "**Inerti Reference Frames**":

- E.g. observe a puck laying still on a horizont sheet of ice in a car. As long as the car is stationary or driving with constant velocity, puck stays still.

  However, whenever the car accelerates (e.g brakes for a red light or makes a turn), the will move WITH RESPECT TO THE FRAME THE CAR, because it "tries to keep going wi its original velocity"!

  Clearly the accelerating car is NOT a frame reference for which the 1st Law is valid…

- We, in fact turn this around, and define an Inertial Reference Frame, as a frame in whi the 1st Law is valid…

- Inertial Reference Frames differ from each other only by constant relative velocities…
- A reference frame fixed to Earth is a "reasonably good" inertial reference frame: effects of Earth's rotation are generally sm

  A better IRF is a frame "fixed to the far stars"…

2nd Law

- 2nd Law:

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

  - The net force $\mathbf{F}_{Net} = \Sigma_i \mathbf{F}_i$ applied on an object results in an acceleration $\mathbf{a}$ of the object, in the same direction as the net force, and with magnitude a proportional to the applied force.
  - The proportionality constant is called the "**mass**" m of the object, and is a (scalar) property of the particular object alone.
  - the vector equation can be written in components as:

$$\sum_i F_{x,i} = ma_x, \quad \sum_i F_{y,i} = ma_y, \quad \sum_i F_{z,i} = ma_z$$

  - SI Units:
    Acceleration a: $\mathrm{m/s^2}$
    Mass m: kg (kilogram)
    Force F: $\mathrm{N} \equiv \mathrm{kg\ m/s^2}$ (Newton)
  - Note, that the 2nd Law includes the 1st Law: if $\mathbf{F}_{Net} = 0$ then **zero acceleration:** $\mathbf{a} = 0$

Examples

A 1200 kg car travels north on a straight road at 35 mi/hr, and brakes for a red light. Assume the braking to be a constant deceleration lasting 5.0 s.

Questions:

- average acceleration?

$$\mathbf{v}(=0) = \mathbf{v}_0(=35\mathbf{i}\,\text{mi/hr} = 15.6\,\text{m/s}) + \mathbf{a}t(=5.0\,\text{s})$$

$$\Rightarrow \quad \mathbf{a} = -\mathbf{v}_0/t = 15.6\mathbf{i}\,\text{ms}^{-1}/5.0\,\text{s} = -3.1\mathbf{i}\,\text{m/s}^2$$

- braking distance?

$$D = x - x_0 = \left(v_x^2 - v_{0x}^2\right)\Big/a_x$$

$$= \left(0 - (15.6\text{ m/s})^2\right)/(-3.1\text{ m/s}^2) = 79\,\text{m}$$

- braking force (incl. direction)?

$$\mathbf{F} = m\mathbf{a} = 1200\,\text{kg} \times (-3.1\,\text{m/s}^2)\mathbf{i} = -3.72 \times 10^3\mathbf{i}\,\text{N}$$

- what object in the problem applies this force on the car? The roadway…