PHYC10003 Physics 1

Lecture 6: Force

Newton’s Third Law of Motion

SSLC-Staff-Student Liaison Committee

- Each Lecture Stream elects a student representative
- Student rep reports on lectures, practicals, tutorials, teaching materials or anything of concern
- Committee meets twice a Semester
- Report goes direct to Head of School of Physics
- We really do want to make the entire subject as effective as possible.
- There's pizza.

Last Lecture

- Relative frames
- Force and superposition
- Newton's First Law
- Inertial frames, mass and motion
- Newton's Second Law
- Force and acceleration
- Free body diagrams
- Gravitational force

5-2 Force – normal forces

- The **normal force**:
  - If you are standing on a surface, the push back **on** you from the surface (due to deformation) is the normal force
  - Normal means perpendicular

When a body presses against a surface, the surface (even a seemingly rigid one) deforms and pushes on the body with a normal force $\vec{F}_N$ that is perpendicular to the surface.

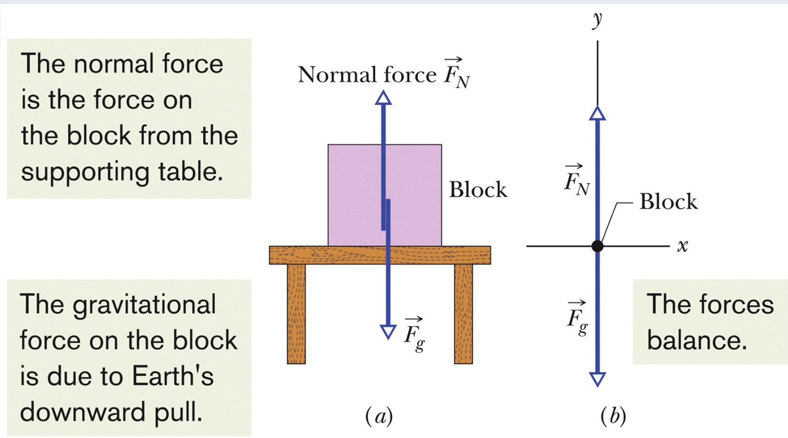


Figure 5-7

5-2 Force – normal forces

Example Normal force for a block resting on a horizontal surface that is:

- Accelerating vertically at a_y: $$F_N = mg + ma_y = m(g + a_y)$$ **Eq. (5-13)**
- Vertically at rest: $$F_N = mg.$$ **Eq. (5-14)**

Checkpoint 3

In Fig. 5-7, is the magnitude of the normal force $\vec{F}_N$ greater than, less than, or equal to mg if the block and table are in an elevator moving upward (a) at constant speed and (b) at increasing speed?

Answer: (a) equal to *mg* (no acceleration)

(b) greater than *mg* (see 5-13, with positive acceleration)

5-2 Force - friction

- **Frictional force** or **friction**:
  - Occurs when one object slides or attempts to slide over another
  - Directed along the surface, opposite to the direction of intended motion

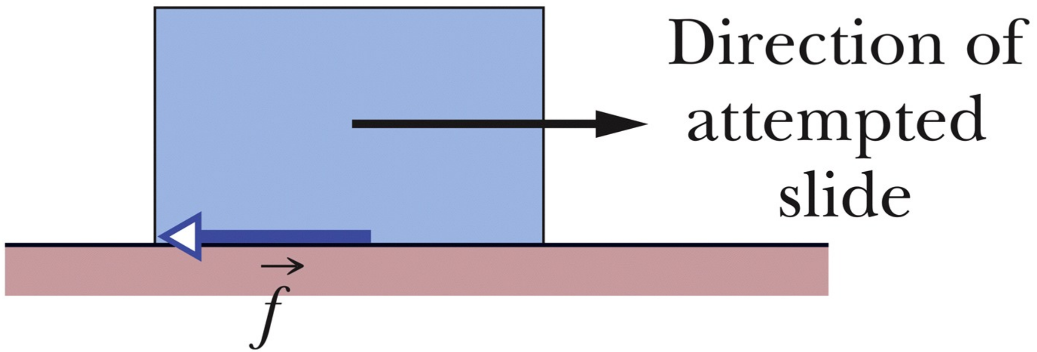


Figure 5-8

5-2 Force - Tension

- **Tension force**:
  - A cord (or rope, etc.) is attached to a body and pulled taut
  - Cord pulls on the body with force *T* directed along the cord
  - The cord is said to be *under tension*
  - The tension in the cord is *T*
- A *massless* and *unstretchable* cord exists only as a connection between two bodies
  - It pulls on both with the same force, *T*
  - True even if the bodies and cord are accelerating, and even if the cord runs around a *massless, frictionless pulley*
  - These are useful simplifying assumptions

5-2 Force - tension

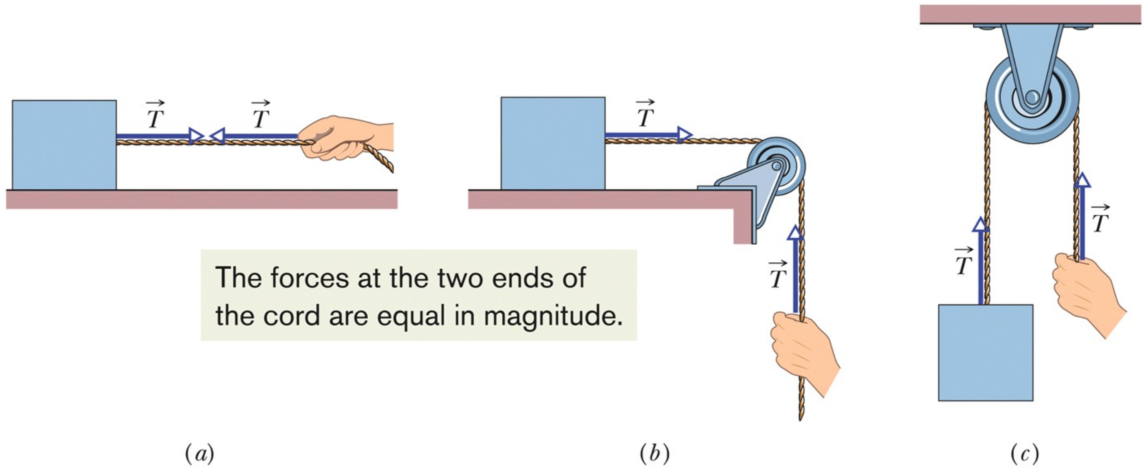


Figure 5-9

Checkpoint 4

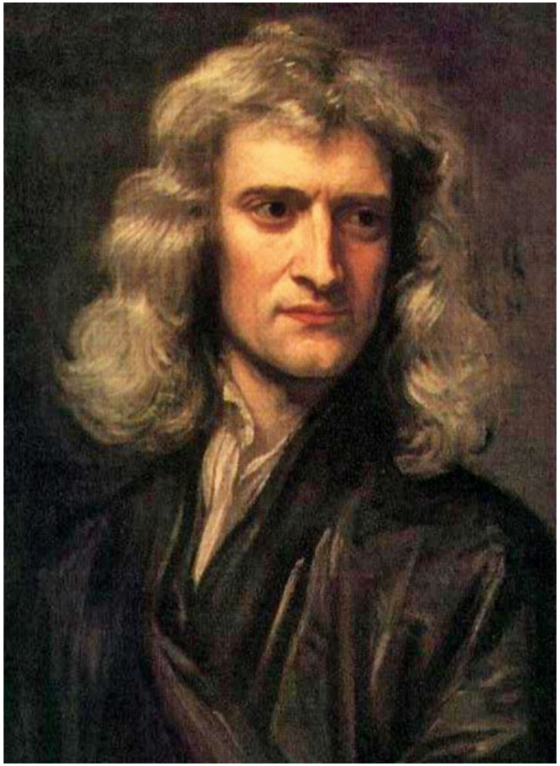
The suspended body in Fig. 5-9*c* weighs 75 N. Is *T* equal to, greater than, or less than 75 N when the body is moving upward (a) at constant speed, (b) at increasing speed, and (c) at decreasing speed?

$T=75N$ $T>75N$

$T<75N$

Answer: (a) equal to 75 N (b) greater than 75 N (c) less than 75 N

5-3 Newton's Third Law of Motion



"For every action there is an equal and opposite reaction"

Isaac Newton by Godfrey Kneller (1646) : (Image-WikiCommons)

5-3 Action and reaction

- Objects *interact* when they push or pull on each other:

Newton's Third Law: When two bodies interact, the forces on the bodies from each other are always equal in magnitude and opposite in direction.

- We can write this law as a scalar or vector relation:

$$F_{BC} = F_{CB} \qquad \vec{F}_{BC} = -\vec{F}_{CB} \qquad \textbf{Eq. (5-15)}$$

- We call these two forces a **third-law force pair**
- Any time any two objects interact, there is a third-law force pair

5-3 Forces – Newton's Third Law of Motion

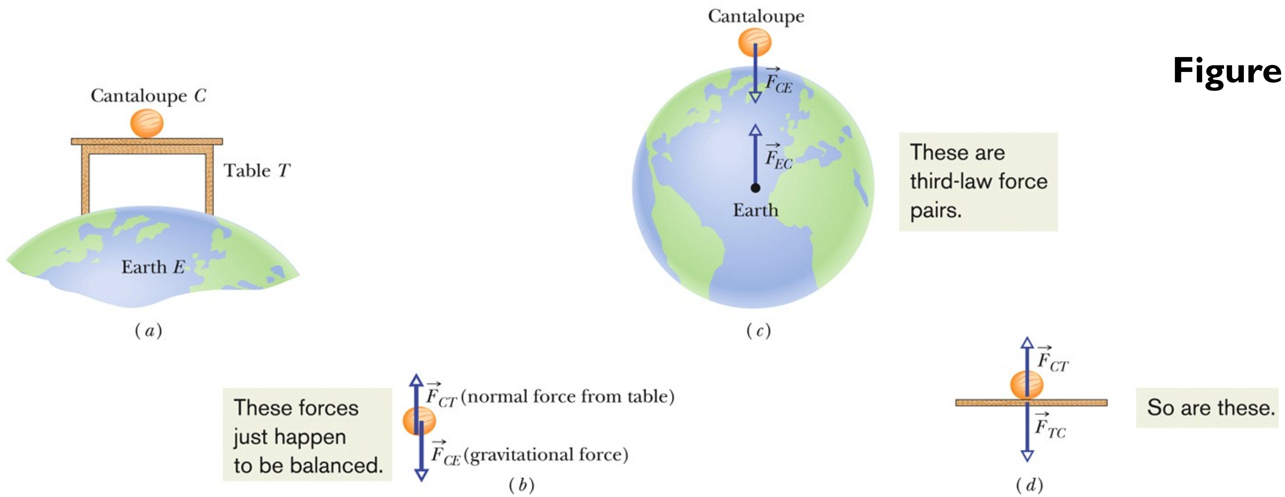


Figure 5-11

- Third-law force pairs:

$$\vec{F}_{CT} = -\vec{F}_{TC} \qquad \text{(cantaloupe–table interaction).}$$

$$\vec{F}_{CE} = -\vec{F}_{EC} \qquad \text{(cantaloupe–Earth interaction).}$$

- Reciprocal gravitational forces between Earth and the cantaloupe

5-3 Forces – action and reaction

Sample Problem A block of mass M = 3.3 kg, connected by a cord and pulley to a hanging block of mass m = 2.1 kg, slides across a frictionless surface

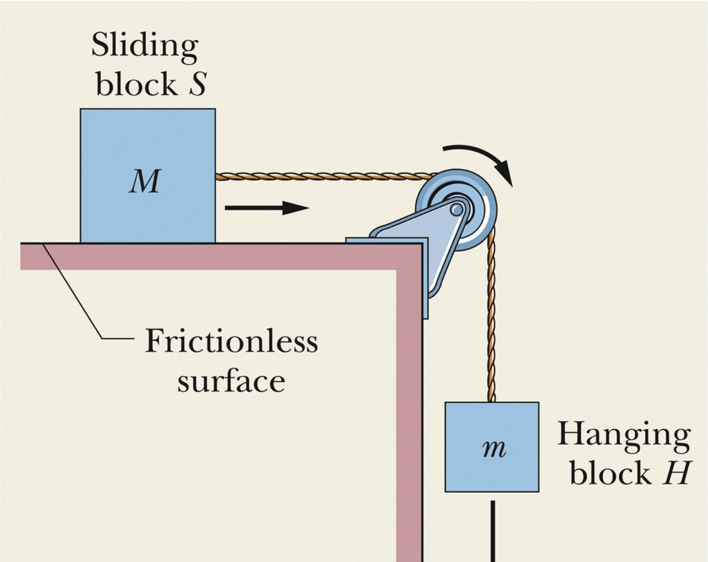


Figure 5-12

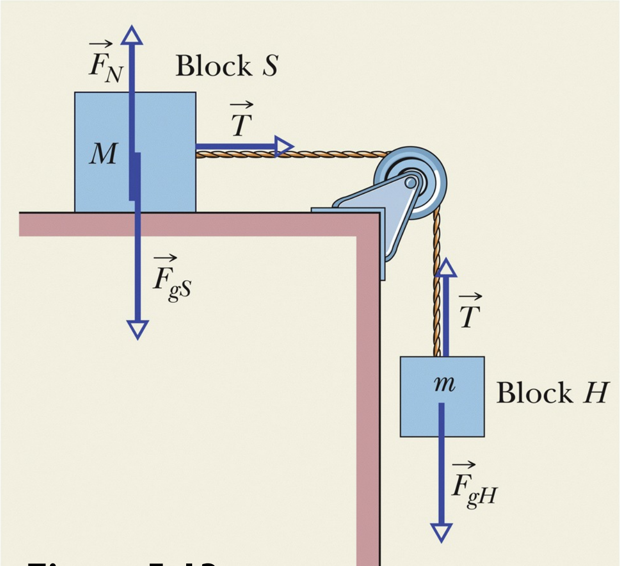


Figure 5-13

5-3 Forces – resolution of forces

- Draw the forces involved
- Treat the string as unstretchable, the pulley as massless and frictionless, and each block as a particle
- Draw a free-body diagram for each mass
- Apply Newton's 2nd law ($F = ma$) to each block → 2 simultaneous eqs.
- Eliminate unknowns (T) that are the same, and solve for the acceleration

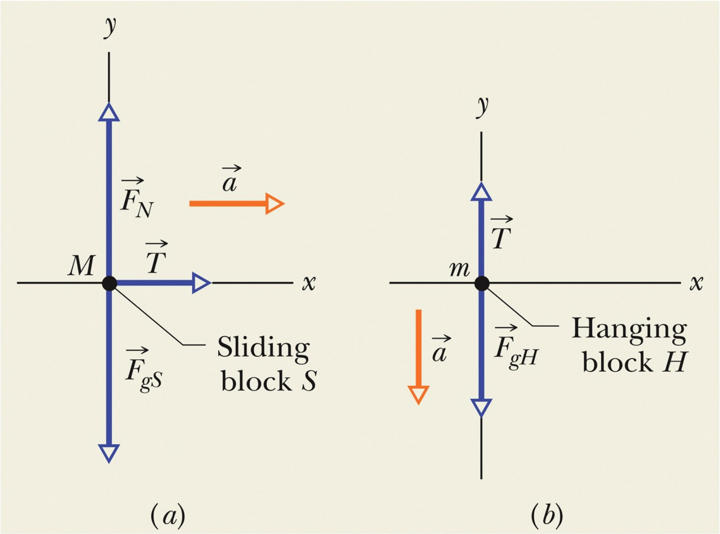


Figure 5-14

5-3 Forces – resolution of forces

- For the sliding block:

$$T = Ma.$$ Eq. (5-18)

- For the hanging block:

$$T - mg = -ma.$$ Eq. (5-20)

- Combining we get:

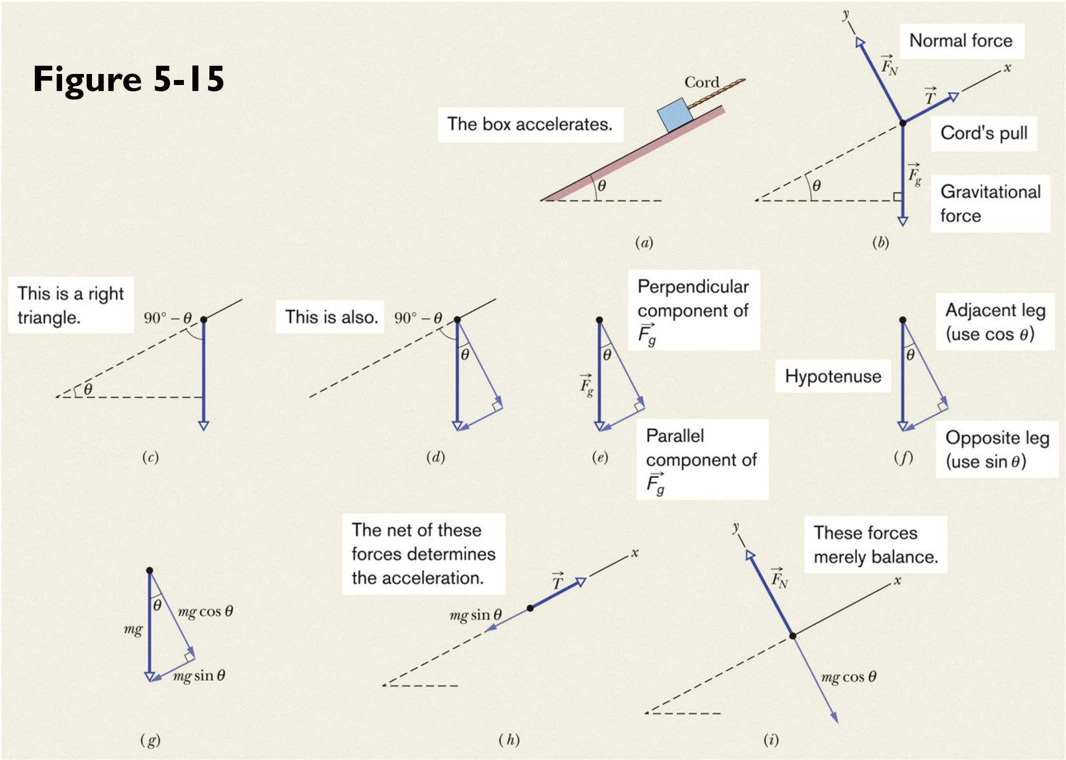
$$a = \frac{m}{M + m} g.$$ Eq. (5-21)

$$T = \frac{Mm}{M + m} g.$$ Eq. (5-22)

- Plugging in we find a = 3.8 m/s^2 and T = 13 N
- **Check!** Check that dimensions are correct, check that a < g, check that $T < mg$ (otherwise acceleration would be upward), check limiting cases (e.g., $g = 0$, $M = 0$, $m = \infty$)

5-3 Forces –resolution of forces

Sample Problem A block being pulled up a ramp:



2-6 Motion: Graphical Approach

Given a graph of an object's acceleration *a* versus time *t*, we can integrate to find velocity

- The Fundamental Theorem of Calculus gives:

$$v_1 - v_0 = \int_{t_0}^{t_1} a\, dt$$

Eq. (2-27)

- The definite integral on the right can be evaluated from a graph:

$$\int_{t_0}^{t_1} a\, dt = \begin{pmatrix}\text{area between acceleration curve} \\ \text{and time axis, from } t_0 \text{ to } t_1\end{pmatrix}$$

Eq. (2-28)

2-6 Motion: Graphical Approach

- **Integrating velocity**:
  - Given a graph of an object's velocity v versus time t, we can integrate to find position
- The Fundamental Theorem of Calculus gives:

$$x_1 - x_0 = \int_{t_0}^{t_1} v \, dt$$

Eq. (2-29)

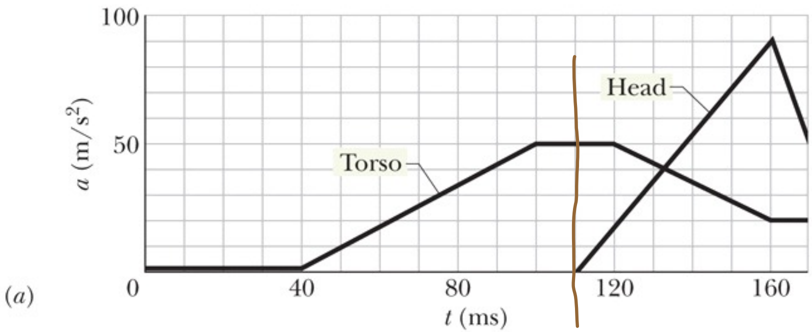
- The definite integral on the right can be evaluated from a graph:

$$\int_{t_0}^{t_1} v \, dt = \begin{pmatrix} \text{area between velocity curve} \\ \text{and time axis, from } t_0 \text{ to } t_1 \end{pmatrix}$$

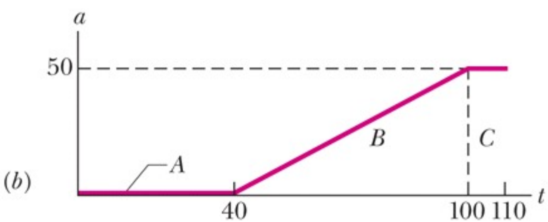
Eq. (2-30)

2-6 Motion: Graphical Approach

Example



The total area gives the change in velocity.



- The graph shows the acceleration of a person's head and torso in a whiplash incident.
- To calculate the torso speed at t = 0.110 s (assuming an initial speed of 0), find the area under the pink curve:

area A = 0

area B = 0.5 (0.060 s) (50 m/s^2) = 1.5 m/s

area C = (0.010 s) (50 m/s^2) = 0.50 m/s

total area = 2.0 m/s

2-6 Motion: Algebraic approach

A particle of mass, *m* ,moves in one dimension. It is subjected to a force, *F*. The force could be *F(t)* or even *F(x(t))*, where x(t) defines the motion of the particle.

Sample the motion at regular times, t_i, for *i* =0,1,2,…such that t_{i+1}-t_i = Δt. Set t_0=0.

If Δt is sufficiently small, then we may write

$$v_i = \frac{x_{i+1} - x_i}{\Delta t}$$

$$a_i = \frac{v_i - v_{i-1}}{\Delta t} = \frac{x_{i+1} + x_{i-1} - 2x_i}{(\Delta t)^2}$$

We can express the velocity and the acceleration *directly* in terms of the sample values of the position, x_i at the time samples, t_i, provided that Δt is small enough.

2-6 Motion: Algebraic approach

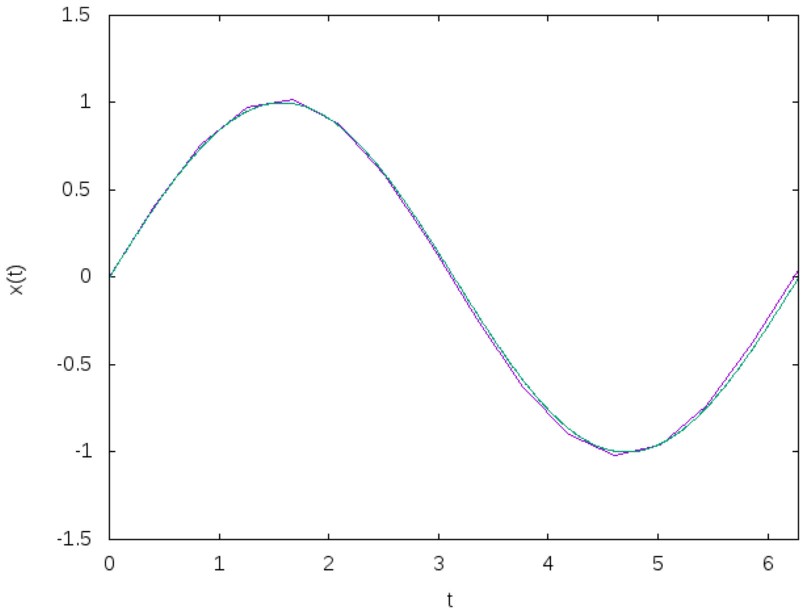
$$F_i = ma_i$$

Substituting for a_i leads to

$$x_{i+1} = 2x_i - x_{i-1} + \frac{F_i}{m}(\Delta t)^2$$

- If we know x_0 and v_0 we may determine x_1
- If we know x_0, x_1 and F_1 we may determine x_2
- If we know x_1, x_2 and F_2 we may determine x_3
- …and so on!

2-6 Motion: Algebraic approach



Algebraic solution (purple, 15 points) for F = - kx, assuming x_0=0, $v_0 = 1.0\ m/s$, $t_{max} = 2\pi\ s$, m=1.0 kg, k=1.0 N/m. The *exact* solution is shown in green (the two solutions are essentially indistinguishable) .

This was a simple problem and more sophisticated methods are used in practice, but they are generally based on the same algebraic method (Euler's method).

Summary

Newtonian Mechanics

- Forces are pushes or pulls
- Forces cause acceleration

Force

- Vector quantities
- $1 \text{ N} = 1 \text{ kg m/s}^2$
- Net force is the sum of all forces on a body

Newton's First Law

- If there is no net force on a body, the body remains at rest if it is initially at rest, or moves in a straight line at constant speed if it is in motion.

Inertial Reference Frames

- Frames in which Newtonian mechanics holds

Summary

$$\vec{F}_{\text{net}} = m\vec{a}$$ **Eq. (5-1)**

Some Particular Forces

- Weight:
- Normal force from a surface
- Friction along a surface
- Tension

$$W = mg$$ **Eq. (5-12)**

Newton's Third Law

- Law of force-pairs
- If there is a force **by** *B* **on** *C*, then there is a force **by** *C* **on** *B*:

$$\vec{F}_{BC} = -\vec{F}_{CB}$$ **Eq. (5-15)**

Graphical and algebraic representation of motion

Preparation for the next lecture

1. Read 6-1 to 6-3 of the text
2. You will find short answers to the odd-numbered problems in each chapter at the back of the book and further resources on LMS. You should try a few of the simple odd numbered problems from each section (the simple questions have one or two dots next to the question number).