

Chapter 4

Force and Newton's Laws of Motion

(Continuation)

Ch 4 Force and Motion

- Newton's 1st Law and 2nd law
- Newton's 3rd Law
- Internal and External forces
- Common Forces
- Applications

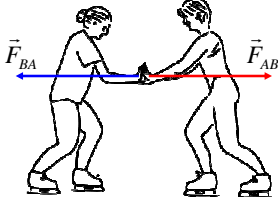
Newton's 1st and 2nd Laws

- Newton's 1st law: an object will
 - stay at rest, or
 - maintain its motion at a constant velocity and in a straight line
 as long as
 - no force is exerted on the object, or
 - all forces cancel each other ($F_{net}=0$)
- Newton's 2nd law:

$$\vec{F}_{net} = m\vec{a}$$
- Galilei Relativity: Laws of Physics take the same form in all inertial frames

Newton's Third Law

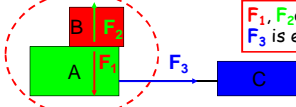
- For each **action** there is a **reaction!**
 - They are equal in magnitude. $|\vec{F}_{AB}| = |\vec{F}_{BA}|$
 - They are opposite in direction. $\vec{F}_{AB} = -\vec{F}_{BA}$
 - They are applied in different bodies.



Third-law Force Pair

A System of Bodies

- **Definition:** two or more bodies that are considered as one entity.
- Forces acting between bodies internal to the system are **internal forces**
- If an external body acts on a body of the system, the force is called an **external force**
- When applying Newton's second law to a system, we consider only the external forces (why?).

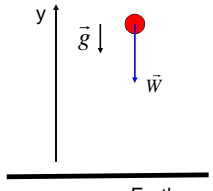


F_1, F_2 are internal for the AB-system
 F_3 is external for the AB-system

Gravitational Force \vec{W}

- **When:** interaction between any two bodies with mass (apple + Earth).
- **Direction:** towards the center of the planet (downwards)
- **Application point:** at the center of mass of the body.
- **Magnitude:** A free falling body (neglect air) drops with a constant acceleration g pointing towards the center of the Earth.

$$\vec{W} = m\vec{g} = -mg\hat{y}$$

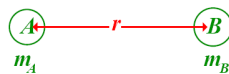


Earth

- g is the free-fall acceleration

Gravitation

- Main result:



"Newton's law of gravitation"

$$F_{AB} = G \frac{m_A m_B}{r^2} \quad \text{attractive}$$

$$G = 6.67 \times 10^{-11} \frac{\text{N} \cdot \text{m}^2}{\text{kg}^2}$$

applies to any masses A+B anywhere !

Notice:

- $F \propto 1/r^2$
- $F \propto m_A m_B$

Applications of Universal Gravitation

- Gravitational force on Earth surface

$$W = G \frac{m m_E}{R_E^2}$$

$$mg = G \frac{m m_E}{R_E^2} \quad \text{take } g = 9.8 \text{ m/s}^2$$

$$g = G \frac{m_E}{R_E^2} \quad R_E = 6380 \text{ km}$$

$$m_E = \frac{g R_E^2}{G} \Rightarrow m_E = 6 \times 10^{24} \text{ kg}$$


Why can we take $g = \text{const.}$ at earth's surface?

Newton says force on mass m a distance r from center of earth is $F = \left(\frac{G m M_E}{r^2} \right)$

But earlier we said $F = mg$

So it must be that $g = \frac{G M_E}{r^2} \neq \text{const.}$

A: We assumed $h \ll R_E$



$$r = R_E + h$$

$$g = \frac{G M_E}{(R_E + h)^2} \approx \frac{G M_E}{R_E^2}$$

Applications of Universal Gravitation

- Acceleration due to gravity g will vary with altitude

Altitude (km) ^a	g (m/s ²)
1 000	7.33
2 000	5.68
3 000	4.53
4 000	3.70
5 000	3.08
6 000	2.60
7 000	2.23
8 000	1.93
9 000	1.69
10 000	1.49
50 000	0.13

$$g(r) = G \frac{M_E}{r^2}, r \geq R_E$$

^aAll figures are distances above Earth's surface.

The Normal Force \vec{N} or \vec{F}_N

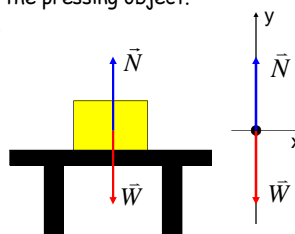
- Force:
 - When: supporting surface
 - Direction: normal to the supporting surface
 - Application point: in the pressing object.
 - Magnitude: reactive

$$\vec{F}_{net} = m\vec{a}$$

$$F_{net,y} = ma_y$$

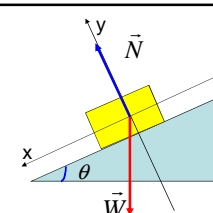
$$N - W = 0$$

$N = W = mg$



Example

- A 0.2 kg block is sliding along a frictionless surface that is inclined at an angle $\theta = 30^\circ$. Find the normal F_N force.



$$\vec{F}_{net} = m\vec{a}$$

$$F_{net,y} = ma_y, \quad a_y = 0$$

$$F_{net,y} = N - W \cos \theta$$

$$N - W \cos \theta = 0$$

$N = mg \cos \theta = 0.2 \cdot 10 \cos 30 = 1.41$

Friction \vec{f}

- When:** when in contact with a rough surface.
 - Slippery surface - no friction!
- Application point:** along the surface of contact.
- Direction:** opposite to the attempted slide.
- Magnitude:** see next slide

The diagram shows a rabbit on the left and a yellow block on the right. For the rabbit, a red arrow labeled \vec{f} points to the right and a blue arrow labeled \vec{v} points to the left. For the block, a red arrow labeled \vec{f} points to the left and a blue arrow labeled \vec{v} points to the right.

Properties of Friction \vec{f}

- Static Friction**
 - Varies in magnitude
 - Along contact surface
 - Depends on other forces (reactive)
 - Has maximum value: $f_{s,max} = \mu_s F_N$
- If sum of other forces exceeds $f_{s,max}$
 - Body starts to move
 - Kinetic friction

Properties of Friction \vec{f}

- Kinetic Friction**
 - Once the body starts sliding, the friction force rapidly decreases
 - Parallel to contact surface
 - Magnitude depends on normal force
- Friction coefficients depend on both contact surfaces
 - $f_k = \mu_k F_N$
 - $\mu_k < \mu_s$
 - dimensionless
 - Independent of velocity, acceleration

Tension \vec{T}

- When:** when pulling an object with a inelastic cord or string.
- Application point:** the point of attachment
- Direction:** along the string and away from the body
- Magnitude:** it is equal to the force with which we pull. The magnitude of the tension is the same at all points of the cord (if the cord is massless).

The diagram shows three scenarios of tension: 1) A hand pulling a block to the right with a red arrow \vec{T} . 2) A hand pulling a block upwards with a red arrow \vec{T} . 3) A pulley system with a block hanging from a cord, with red arrows \vec{T} pointing up at both ends.

Example

- Two blocks with masses m_A , and m_B are connected with a cord that is wrapped around a massless frictionless pulley. Find the acceleration, a of the blocks.

$$\vec{F}_{A,net} = m_A \vec{a} \quad \vec{F}_{B,net} = m_B \vec{a}$$

$$T - W_A = m_A a \quad T - W_B = -m_B a$$

$$T = W_A + m_A a \quad T = W_B - m_B a$$

$$W_A + m_A a = W_B - m_B a$$

$$a = g(m_B - m_A) / (m_A + m_B)$$

A diagram showing a pulley at the top. A green block labeled 'A' is on the left side of the cord, and a yellow block labeled 'B' is on the right side. Blue arrows represent weight forces \vec{W}_A and \vec{W}_B pointing down from each block. Red arrows represent tension forces \vec{T} pointing up from each block. A vertical y-axis is shown to the right of the pulley.

Applying Newton's Laws-Example

- A block with mass $m=1$ kg is pulled up an inclined surface with an acceleration $a=1$ m/s². The tension in the cord should not exceed 6 N. What is the maximum friction that is allowed? ($\theta=30^\circ$)

A free body diagram of a block on an inclined plane. The plane makes an angle θ with the horizontal. Forces acting on the block are: tension \vec{T} up the incline, weight \vec{W} vertically down, normal force \vec{F}_N perpendicular to the incline, and friction \vec{f} down the incline. A coordinate system with x-axis up the incline and y-axis perpendicular to it is shown. The acceleration \vec{a} is also shown pointing up the incline.

$$\vec{F}_{net} = m\vec{a}$$

$$\vec{W} + \vec{F}_N + \vec{f} + \vec{T} = m\vec{a}$$

$$T - W \sin \theta - f = ma \quad (x)$$

$$-W \cos \theta + F_N = 0 \quad (y)$$

$$f = -ma + T - W \sin \theta = 0.1N$$