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

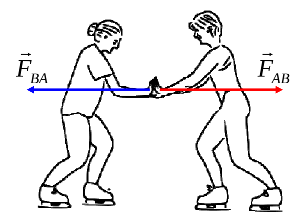
  as long as
  - no force is exerted on the object, or
  - all forces cancel each other ($F_{net}=0$)
- Newton's 2nd law:

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

- Galilei Relativity: Laws of Physics take the same form in all inertial frames

Newton's Third Law

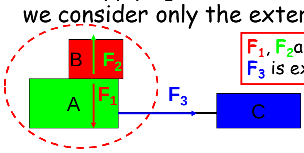
- For each action there is a reaction!
  - They are equal in magnitude. $|\vec{F}_{AB}| = |\vec{F}_{BA}|$
  - They are opposite in direction. $\vec{F}_{AB} = -\vec{F}_{BA}$
  - They are applied in different bodies.



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?).

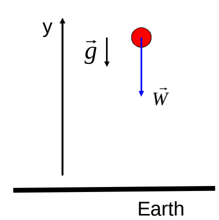


F_1, F_2 are internal for the AB-system
F_3 is external for the AB-system

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.

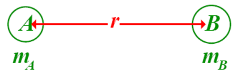
$$\vec{W} = m\vec{g} = -mg\hat{y}$$



- g is the free-fall acceleration

Gravitation

- Main result:



"Newton's law of gravitation"

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

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

applies to any masses A+B anywhere !

Notice:
1) $F \propto 1/r^2$
2) $F \propto m_A m_B$

Applications of Universal Gravitation

• Gravitational force on Earth surface

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

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

take $g = 9.8\, m/s^2$

$R_E = 6380\, km$

$\Rightarrow m_E = 6\times 10^{24}$ kg

$$g = G\frac{m_E}{R_E^2}$$

$$m_E = \frac{g R_E^2}{G}$$

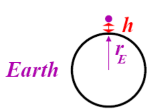
Why can we take g=const. at earth's surface?

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 $g = \frac{G M_E}{r^2} \neq const.$

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

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

TABLE 7.1

Free-Fall Acceleration g at Various Altitudes

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

[a] All figures are distances above Earth's surface.

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

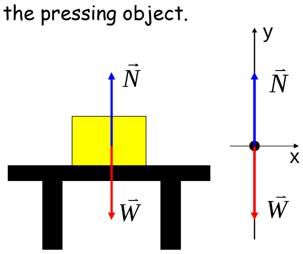
- Force:
  - When: supporting surface
  - Direction: normal to the supporting surface
  - Application point: in the pressing object.
  - Magnitude: reactive

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

$$F_{net,y} = m a_y$$

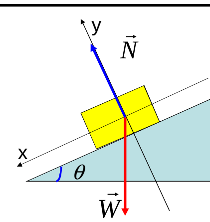
$$N - W = 0$$

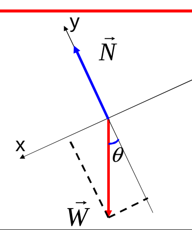
$$N = W = mg$$



Example

- A 0.2 kg block is sliding along a frictionless surface that is inclined at an angle θ=30°. Find the normal F_N force.





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

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

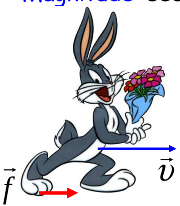
$$F_{net,y} = N - W\cos\theta$$

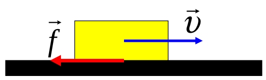
$$N - W\cos\theta = 0$$

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

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





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 $\vec{f}$

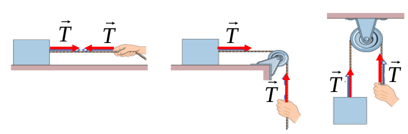
- Kinetic Friction
  - Once the body starts sliding, the friction force rapidly decreases
  - Parallel to contact surface
  - Magnitude depends on normal force

$$f_k = \mu_k F_N$$

- Friction coefficients depend on both contact surfaces
  - $\mu_k < \mu_s$
  - 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).



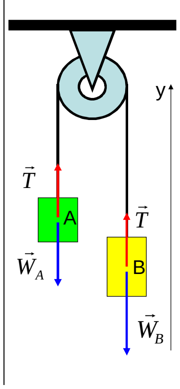
Example

- 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.

$\vec{F}_{A,net} = m_A \vec{a}$	$\vec{F}_{B,net} = m_B \vec{a}$
$T - W_A = m_A a$	$T - W_B = -m_B a$
$T = W_A + m_A a$	$T = W_B - m_B a$

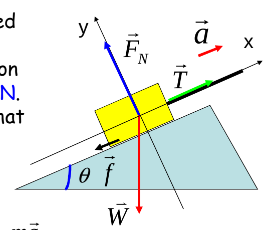
$$W_A + m_A a = W_B - m_B a$$

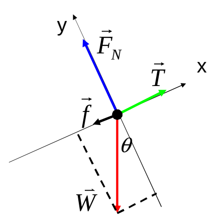
$$a = g(m_B - m_A)/(m_A + m_B)$$



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? (θ=30°)





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

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

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

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

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