Chapter 1　Introduction

◎ 1-1　What is Physics?

Physics：study composition of **Matter** and **Interactions** between particles.

1. Elementary Particles：
   6 leptons：electron, electron neutrino, muon, muon neutrino, tauon, tauon neutrino
   6 quarks：up, down, charm, strange, top, bottom
   12 antiparticles
2. Fundamental Interactions：
   Gravitational, Electromagnetic, Strong, and Weak

Category of Physics：Classical Physics and Modern Physics.

1. Classical Physics：Mechanics, Thermodynamics, (Optics), and Electromagnetism.
2. Modern Physics：Relativity and Quantum Physics.

◎ 1-2　Units

SI Unit

Measurements → standards or units

International System of Units (SI unit)

Base units：

Physical Quantity	Name	Symbol
Length	**meter**	**m**
Mass	**kilogram**	**kg**
Time	**second**	**s**
Temperature	**ampere**	**A**
Electric Current	**kelvin**	**K**
Amount of Substance	**mole**	**mol**
Luminous Intensity	candela	Cd

Definitions:

Meter (m): The meter is the distance traveled by light in vacuum in a time interval of 1/299 792 458 of a second. (1983)

Kilogram (kg): The mass of the international prototype of the kilogram. (1889)

Second (s): The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom. (1967)

Ampere (A): The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross section, and placed 1 m apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per meter of length. (1948)

Kelvin (K): The kelvin, the unit of thermodynamics temperature, is the fraction 1/273.16 of the thermodynamics temperature of the triple point of water. (1957)

Candela (Cd): The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian. (1979)

Mole (mol): The mole is the amount of a substance that contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12. (1971). The entities may be atoms, molecules, ions, electrons, or other particles.

Derived units：combination of base units

For example, the SI unit of force is called the newton (N), N = kg·m/s^2 (use $F = ma$)

For example, the SI unit of energy or work is called the joule (J)

J = N·m = kg·m^2/s^2 (use $W=F\cdot\Delta s$)

DERIVED UNITS WITH SPECIAL NAMES

Quantity	Derived Unit	Name
Activity	1 decay/s	Bequerel (Bq)
Capacitance	C/V	farad (F)
Charge	A.s	coulomb (C)
Electric Potential; EMF	J/C	volt (V)
Energy, work	N.m	joule (J)
Force	kg.m/s^2	newton (N)
Frequency	l/s	hertz (Hz)
Inductance	V.s/A	henry (H)
Magnetic flux density	Wb/m^2	tesla (T)
Magnetic flux	V.s	weber (Wb)
Power	J/s	watt (W)
Pressure	N/m^2	pascal (Pa)
Resistance	V/A	ohm (Ω)

Dimensional Analysis

Dimension:

For example, N = kg·m/s^2, the dimension of force is【F】=MLT^{-2}

An equation must be dimensionally consistent.

e.g. $s = at^2/2 \Rightarrow$ L = (LT^{-2})(T^2) = L or m = (m/s^2)(s^2) = m

◎ 1-3 Power of 10 Notation and Order of Magnitude

SI Prefixes：

Factor	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}
Prefix	peta	tera	giga	mega	kilo	centi	milli	micro	nano	pico	femto
Symbol	P	T	G	M	K	c	m	μ	n	p	f

Order of magnitude → Building physical intuition

Length		Mass		Time	
size of a nucleus	10^{-15} m =1 fm	electron	9×10^{-31} kg	lifetime of a excited state	10^{-8} s
size of an atom	10^{-10} m =1 Å	proton	2×10^{-27} kg	age of Earth	1.3×10^{17} s
length of a virus	10^{-8} m	speck of dust	10^{-9} kg	age of the universe	5×10^{17}
size of a cell	10^{-6} m = 1 μm	truck	10^{3} kg		
thickness of a paper	10^{-4} m = 0.1 mm	Earth	6×10^{24} kg		
radius of Earth	6.4×10^{6} m	Sun	2×10^{30} kg		
distance to the nearby star	4×10^{16} m = 4.6 l.y.	known universe	10^{53} kg		

◎ 1-4 Reference Frames and Coordinate System

The position of a body has meaning only in relation to a **frame of reference** — a table, a room, a moving car, or the earth itself.

A **coordinates system**—a set of axes to specify the position of a body or the vector of a physical quantity..

Cartesian coordinate system—*x*, *y*, and *z* axis, mutually perpendicular.

Chapter 2 Kinematics

Kinematics：study the **motion** of the body.
Motion：**Translation**, **Rotation**, and **Vibration**.
See **Fig. 3.1**
For the translation of an object,
the object $\rightarrow$ a **particle**

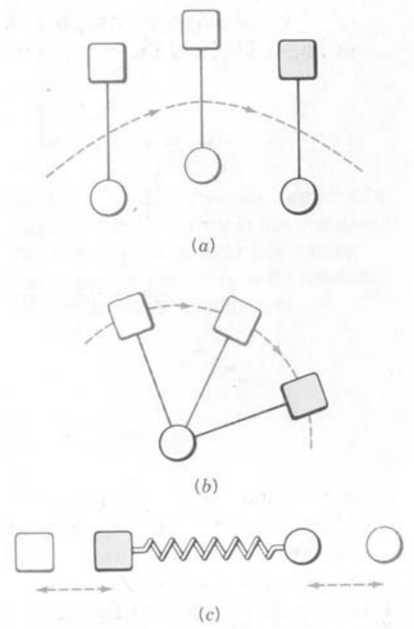


FIGURE 3.1 The motion of a body may involve (a) translation, (b) rotation, (c) vibration, or a combination of these.

◎ 2-1　Two Equations

$$\boxed{\vec{v}(t)=\frac{d\vec{r}(t)}{dt}} \Leftrightarrow \boxed{\vec{r}(t)=\int \vec{v}(t)dt+\vec{r}_0} \quad \textbf{[2-1]}$$

$$\boxed{\vec{a}(t)=\frac{d\vec{v}(t)}{dt}} \Leftrightarrow \boxed{\vec{v}(t)=\int \vec{a}(t)dt+\vec{v}_0} \quad \textbf{[2-2]}$$

where $\vec{r}$ ：**position** (vector)
$\vec{v}$ ：(instantaneous) **velocity**
$\vec{a}$ ：(instantaneous) **acceleration**
Note：in general, $\vec{r}$, $\vec{v}$, and $\vec{a}$ are functions of time.

The average velocity $\vec{v}_{av}(t)=\frac{\Delta\vec{r}(t)}{\Delta t}=\frac{\vec{r}_2(t_2)-\vec{r}_1(t_1)}{t_2-t_1}$

the average acceleration $\vec{a}_{av}(t)=\frac{\Delta\vec{v}(t)}{\Delta t}=\frac{\vec{v}_2(t_2)-\vec{v}_1(t_1)}{t_2-t_1}$

where $\Delta\vec{r}=\vec{r}_2-\vec{r}_1$ called **displacement** (note：difference between displacement and **distance** = length of the path)

Compare instantaneous and average value：

$\vec{v}(t)=\frac{d\vec{r}(t)}{dt}=\lim_{\Delta t\to 0}\frac{\Delta\vec{r}}{\Delta t}$ cf. $\vec{v}_{av}(t)=\frac{\Delta\vec{r}(t)}{\Delta t}$ note：Δt is finite, not infinitesimal

Similarly, for instantaneous and average acceleration.

An Equation for Vectors = 3 Equations for Scalars

In 3 dimensions

$$\vec{r}(t)=x(t)\hat{i}+y(t)\hat{j}+z(t)\hat{k}$$

$$\Rightarrow \quad \vec{v}(t)=\frac{d\vec{r}(t)}{dt}=\frac{dx(t)}{dt}\hat{i}+\frac{dy(t)}{dt}\hat{j}+\frac{dz(t)}{dt}\hat{k}=v_x(t)\hat{i}+v_y(t)\hat{j}+v_z(t)\hat{k}$$

i.e. $\quad v_x(t)=dx(t)/dt$

$$v_y(t) = dy(t)/dt$$

$$v_z(t) = dz(t)/dt$$

Similarly,

$$\vec{a}(t) = \frac{d\vec{v}(t)}{dt} = \frac{dv_x(t)}{dt}\hat{i} + \frac{dv_y(t)}{dt}\hat{j} + \frac{dv_z(t)}{dt}\hat{k} = a_x(t)\hat{i} + a_y(t)\hat{j} + a_z(t)\hat{k}$$

i.e. $a_x(t) = dv_x(t)/dt$

$$a_y(t) = dv_y(t)/dt$$

$$a_z(t) = dv_z(t)/dt$$

◎ 2-2 The Equations for Constant Acceleration

For $a(t)$ = constant = a, we have

$$\boxed{v = v_0 + at} \qquad \textbf{[2-3]}$$

$$\boxed{x = x_0 + v_0 t + \frac{1}{2}at^2} \qquad \textbf{[2-4]}$$

and $$\boxed{v^2 = v_0^2 + 2a(x - x_0)} \qquad \textbf{[2-5]}$$

where x_0 : initial position, i.e. position at $t = 0$

v_0 : initial velocity, i.e. velocity at $t = 0$

Derivation :

$$v = \int a dt + v_0 = a\int dt + v_0 = at + v_0$$

$$x = \int v dt + x_0 = \int (v_0 + at)dt + x_0 = v_0 t + \frac{1}{2}at^2 + x_0$$

Use above equations, you can get algebraically

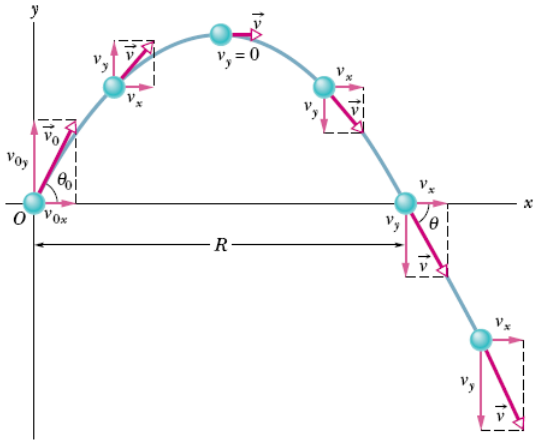
$$v^2 = v_0^2 + 2a(x - x_0)$$

◎ 2-3 Projectile Motion

x direction：constant velocity ($a_x = 0$)

$\Rightarrow$ $v_x = \text{const.} = v_{0x} = v_0\cos\theta_0$

$x = x_0 + v_{0x}t = x_0 + v_0\cos\theta_0 t$



free-fall

y direction：constant acceleration

$a_y = -g$

$\Rightarrow$ $v_y = v_{0y} - gt$

$$y = y_0 + v_{0y}t - \frac{1}{2}gt^2$$

$$v^2 = v_{0y}^2 - 2g(y - y_0)$$

where $v_{0y} = v_0 \sin\theta_0$

Problem 2-1：A ball is thrown at 21 m/s at 30° above the horizontal from the top of a roof 16 m height. Find (a) the time of flight; (b) the horizontal range; (c) the maximum height; (d) the angle at which the ball hits the ground; (e) the velocity when it is 2 m above the roof.

Problem 2-2：A basketball is thrown at 45° above the horizontal. The hoop is located 4 m away horizontally at a height of 0.8 m above the point of release. What is the required initial speed?

◎ 2-4 Uniform Circular Motion

Problem 2-3：The position of a particle in a uniform circular motion can be described as $\vec{r} = R\cos(\omega t)\hat{i} + R\sin(\omega t)\hat{j}$, where R is the radius and ω is called the angular speed. Show that (a) the speed $v = \omega R$; and (b) the acceleration $\vec{a} = -\omega^2\vec{r} = -\dfrac{v^2}{R}\hat{r}$, where the unit vector $\hat{r} = \vec{r}/|\vec{r}|$.

(Hint: $\vec{v} = \dfrac{d\vec{r}}{dt}$ and $\vec{a} = \dfrac{d\vec{v}}{dt}$)

The **Centripetal** acceleration a_r is

$$\boxed{a_r = v^2 / R} \qquad \textbf{[2-6]}$$

the subscript r：the acceleration is radial.

In a vector notation, we write

$$\vec{a}_r = -\frac{v^2}{R}\hat{r} \qquad \textbf{[2-7]}$$

Since $v = 2\pi r/T$, also

$$a_r = 4\pi^2 R / T^2 \qquad [2\text{-}8]$$

where T：the *period*

Nonuniform Circular Motion

For a particle in nonuniform circular motion, i.e. the speed $v \neq$ constant, it has the centripetal acceleration $a_r = v^2 / R$

and the tangential acceleration $a_t = dv / dt$

In general, for a particle moving along a curved path

the centripetal acceleration $a_r = v^2 / r$

and the tangential acceleration $a_t = dv / dt$

where r：radius of curvature of the path at the given point

Chapter 3 Particle Dynamics

Dynamics：explanation → why bodies move?
Kinematics：description → how bodies move?.

◎ 3-1 Newton's Laws of Motion

Newton's First Law and Inertial Frame

Newton's First Law：

Every body continue in its state of rest or of uniform motion in a straight line unless it is compelled to change that state by force impressed upon it.

Mathematical expression:
If the net force $F_{\text{net}} = 0$ on a body
$\Leftrightarrow$ $a = 0$ or v = const.

Inertia：the tendency of a body to resist any change in its state of motion.

Inertial (Reference) Frame (or **Inertial Coordinate System**)：in which Newton's first law is valid. Otherwise, it is a *noninertial* frame.

If S is an inertial frame, any other frame S' moving with constant velocity relative to S, then S' is also an inertial frame.

Newton's 2nd Law

For a particle (in general, a *system*) of mass m

$$\boxed{\sum \vec{F} = m\vec{a}} \qquad [3\text{-}1]$$

i.e.

$$\boxed{\sum F_x = ma_x} \quad \boxed{\sum F_y = ma_y} \quad \boxed{\sum F_z = ma_z} \qquad [3\text{-}2]$$

where $\vec{a}$：acceleration of the particle

$\sum \vec{F} = \vec{F}_{net}$：net force acts on the particle, i.e. sum of all the forces

SI unit for forces：N (newton) = kg·m/s^2

Newton's 3rd Law

$$\boxed{\vec{F}_{AB} = -\vec{F}_{BA}} \qquad \textbf{[3-3]}$$

The force exerted on A by B is equal to and opposite to the force exerted on B by A.

Note：the forces act on different objects.

◎ 3-2 Application of Newton's Laws

Use Newton's Laws to Solve the Problems of Dynamics

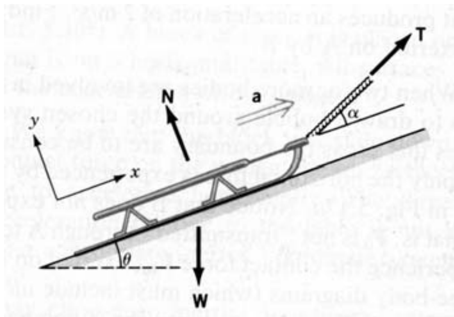
1. Identify the ***system***—one or more bodies as a system.
2. Draw all the *external* forces acting on each body.
3. Select an *inertial* frame.—draw the coordinate axes.
4. Draw a ***free-body diagram*** for each mass.
5. Write the 2nd law in component forms.

$$\sum F_x = ma_x\,; \qquad \sum F_y = ma_y$$

   Solve the equations

6. Check the results：(1) Dimension (i.e. the unit)；(2) Extreme case.

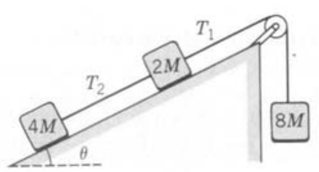
Problem 3-1： A sled of mass 8 kg is on a frictionless slope incline at 35° to the horizontal. by a rope whose tension is 40 N and which make of 20° with the slope (α = 20°). Find the acceleration of the sled and the normal force due incline.



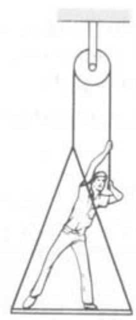
It is pulled an angle

to the

Problem 3-2： Three blocks with masses 4M, 2M, and 8M are connected. The tensions in the ropes are T_1 and T_2. In terms of M, g, and θ, obtain expressions for: (a) the acceleration; (b) $T_1 - T_2$. Ignore friction.



Problem 3-3： A painter of mass M = 75 kg stands on a platform of 15 kg. He pulls on a rope that passes around a pulley. Find the tension in given that (a) he is at rest, or (b) he accelerates upward at 0.4 m/s^2.



mass m =

the rope

◎ 3-3　Friction

Fig.：**Static friction** and **Kinetic friction**　The force of kinetic friction　f_k

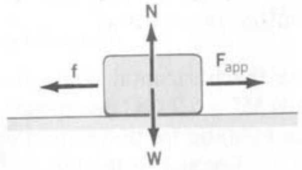


FIGURE 6.3 The force of friction **f** opposes the relative motion of two surfaces in contact.

$$f_k = \mu_k N \qquad [3\text{-}4]$$

The force of static friction　f_s

$$f_{s(max)} = \mu_s N \quad \text{or} \quad f_s \leqq \mu_s N \qquad [3\text{-}5]$$

where　N：normal force

μ_k：the coefficient of kinetic friction

μ_s：the coefficient of static friction

μ_k, μ_s dep. on roughness, cleanliness, temperature, and humidity.

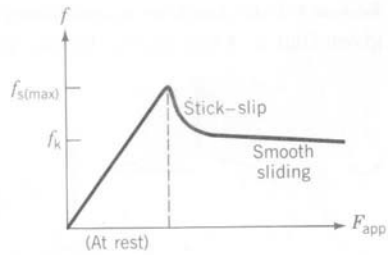
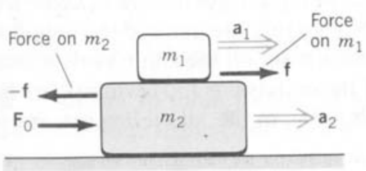
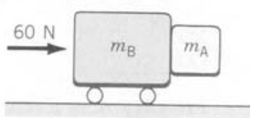


FIGURE 6.4 The variation of the force of friction with the applied force. When the block is at rest the force of static friction f_s balances the applied force F_{app} until it reaches a maximum value. When the block moves, it is subject to the force of kinetic friction.

Problem 3-4：A block of mass m_1 = 2 kg is placed on a block of mass m_2 = 4 kg.　The lower block is on a frictionless horizontal surface and is subject to a force F_0 = 30 N . Find the minimum value of the coefficient of friction such that m_1 does not slide on m_2.



Problem 3-5：Block A of mass m_A = 2 kg is on the front face of cart B of mass m_B = 3 kg. A force of 60 N acts on B. What is the minimum coefficient of friction needed for A not to slide down?



◎ 3-4　Dynamics of Circular Motion

For a particle in circular motion, the centripetal acceleration is

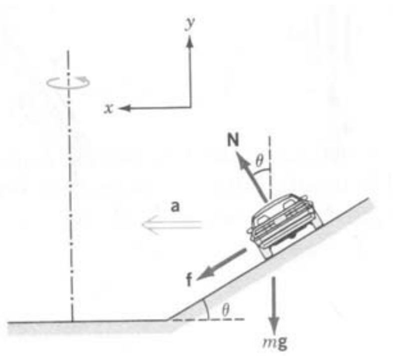
$$\vec{a} = -\frac{v^2}{R}\hat{r}$$

from $\vec{F} = m\vec{a}$, the particle must be subjected to a **centripetal force** of magnitude

$$F = \frac{mv^2}{R}$$

1. 當一粒子作圓周運動時，其在向心方向合力的大小 = mv^2/R —此量稱爲向心力；亦即，其必受到某些力 (可能是張力，重力，摩擦力......) 提供作向心力。
   It is *not* a new force to be added to the free-body diagram.
2. *Centrifugal* force is a noninertial force.

Problem 3-6：A car travels in a horizontal circle around a curve of radius r banked at an angle θ to the horizontal. If μ is the coefficient of static friction, find the maximum speed possible without sliding sideways.



Problem 3-7：A block of mass 0.4 kg is attached to a vertical rotating spindle by two strings of equal length. The period of rotation is 1.2 s. Determine the tension in the strings.