大学物理
简明双语教程

主编◎杨红卫　刘凤艳

[Concise Bilingual Course of University Physics]

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Preface

This book is an English – Chinese concise course of university physics written for engineering students. It is a textbook for teachers who are engaged in bilingual teaching of university physics and students who are learning this course interiorly.

This bilingual textbook has a moderate difficulty, which is easy to teach and learn. The content selection of this book is in accordance with the basic requirements of college physics. The main objective of this textbook is to provide students with a clear and logical presentation of the basic concepts and principles of physics, so we try to reduce infinitesimal calculus and mathematical derivation in order to emphasize physical essence and establish a distinct physical image. A considerable number of examples and exercises are provided to strengthen the understanding of the concepts and principles, and the answers for the exercises are attached at the end of each chapter.

This book is divided into five parts. Part I (chapters 1 – 8) deals with Newtonian mechanics, including the kinematics of mass points, Newton's laws, momentum, work and energy, the rotation of a rigid body about a fixed axis, oscillation and wave, and special relativity; Part II (chapters 9 – 10) is concerned with gas kinetics and thermodynamics; Part III (chapters 11 – 16) covers electricity and magnetism, including electrostatic field, electric potential energy and electric potential, conductors and dielectrics in electrostatic fields, magnetic field, electromagnetic induction; Part IV (chapters 17 – 19) treats wave optics, including interference, diffraction and polarization of light; Part V (chapter 20) represents an introduction to quantum physics.

The editors deeply appreciate Professor Jiang Shaolin for his advice and Dr. Han Shouzhen for his modification of this book. We sincerely hope this textbook is helpful for the students.

We acknowledge the support from the Textbook publishing Foundation of Beijing University of Technology.

前　　言

本书是一本英汉对照的大学物理简明教材，是为工科大学生开设的“大学物理双语教学”课程而编写的，可以作为开设大学物理双语教学课程的老师以及学习大学物理双语课程的学生的教材或参考用书。

本书难度适中、篇幅不长、易教易学。在内容的编写上紧紧围绕大学物理课程的基本要求，系统性强。在讲法上，对物理学中的基本概念和原理的讲述力求简洁明了、言简意赅。书中尽量减少复杂的微、积分运算和数学推导，以突出物理本质，建立鲜明的物理图像。为了加深对基本概念和原理的理解，书中配有一定数量的例题。同时，还提供了不同难度的习题供学生练习，并在每章后面附有答案。

本书共分五部分。第一部分（第1章—第8章）讲述牛顿力学、振动与波和狭义相对论等内容，其中牛顿力学又分为质点运动学、牛顿定律、动量、功和能、刚体的定轴转动；第二部分（第9章—第10章）包括气体动理论和热力学基础；第三部分（第11章—第16章）涵盖了整个电、磁学内容，包括静电场、电势能和电势、静电场中的导体和电介质、磁场和电磁感应；第四部分（第17章—第19章）讲述波动光学的内容，包括光的干涉、衍射以及偏振；第五部分（第20章）简单介绍了量子力学的发展和相关内容。

感谢江少林老师对本书提出的宝贵意见，感谢韩守振老师对本书提出的修改意见。

本书的出版得到了北京工业大学教材出版基金的资助，在此表示衷心的感谢。

限于作者的水平，书中难免有不妥之处，有待不断改进和完善。

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Chapter 1 The Kinematics of Mass Points

Mechanics is the study of the mechanical motion of objects. The part of mechanics that describes motion without regard to its causes is called kinematics. The part of mechanics concerned with the study of the motion of an object and the causes of motion is called dynamics.

When we study the motion of an object, if we may ignore its size and shape, or we may take into account its translational motion only, we may therefore regard the object as a single point with a mass, which is usually called a mass point (particle).

In this chapter we will study only the kinematics of mass points without worrying about what forces cause it to have that particular path. We shall study by introducing position, displacement, velocity and acceleration vectors. These concepts are used to describe the motion of mass points.

1.1 Position Vector

Any quantity with both magnitude and direction is defined to be a vector. Any quantity with a magnitude only, without direction, is defined to be a scalar. In the Cartesian coordinate system of Fig. 1.1, at time t the position of mass point P in the coordinate system is represented by the position vector $\vec{r}(t)$. We see in Fig. 1.1 that the projections of position vector $\vec{r}$ on the Ox, Oy, and Oz axes (i.e. the coordinates of the mass point) are x, y, and z, respectively. If we take $\vec{i}$, $\vec{j}$, and $\vec{k}$ as unit vectors along the Ox, Oy, and Oz axes, then the position vector $\vec{r}$ can also be written as

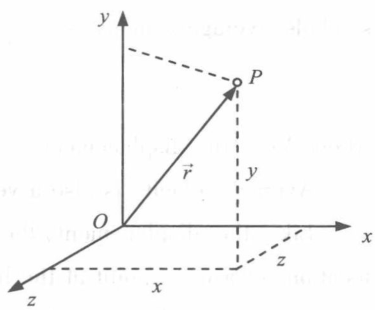

Fig. 1.1 Position vector

$$\vec{r} = x\vec{i} + y\vec{j} + z\vec{k} \tag{1.1}$$

As the mass point moves, its position vector $\vec{r}$ is therefore a function of time, i.e.

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

The above equation is also called the equation of motion of the mass point, while $x(t)$, $y(t)$, and $z(t)$ are the components of the equation of motion. By eliminating the parameter t we obtain the equation of the trajectory of the mass point in the three-dimensional space.

1.2 Displacement

We define displacement $\Delta\vec{r}$ as the change in position vector of a mass point that occurs in an interval. Consider a mass point moving through space as shown in Fig. 1.2. A mass point moves from point A at time t_1 to point B at time t_2, the position vector changes from $\vec{r}_A$ to $\vec{r}_B$. The displacement $\Delta\vec{r}$ that occurs in this interval is

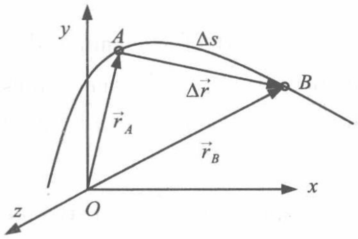

Fig. 1.2 Displacement vector

$$\Delta\vec{r} = \vec{r}_B - \vec{r}_A \tag{1.2}$$

The displacement is determined only by the starting and ending points of the interval. Displacement has a direction as well as a magnitude. Thus it is a vector. Note the difference between displacement $\Delta\vec{r}$ and distance Δs. Distance is the actual length the mass point has gone through. Distance has no direction. So distance is a scalar. In general the magnitude of $\Delta\vec{r}$, i. e. , $|\Delta\vec{r}|$ is not equal to distance Δs. Only when Δt approaches zero, $|\Delta\vec{r}|$ is equal to Δs, i. e. , $|\mathrm{d}\vec{r}| = \mathrm{d}s$.

1.3 Velocity

Average velocity is precisely defined to be displacement divided by the time of travel. In symbols, average velocity is

$$\overline{\vec{v}} = \frac{\Delta\vec{r}}{\Delta t} \tag{1.3}$$

where $\Delta\vec{r}$ is the displacement.

Average velocity is also a vector, and it has the same direction as displacement.

Like the displacement, the average velocity in anytime interval depends only on the locations of a mass point at the beginning and ending of the interval. If a mass point returns to its starting point, then according to the definition of Eq. 1.3 the average velocity is zero.

Average velocity $\overline{\vec{v}}$ may be helpful in considering the overall behavior of a mass point during some interval. In order to describe the details of its motion, we use the instantaneous velocity $\vec{v}$. As Δt approaches zero, the limiting value of the average velocity is called the instantaneous velocity (called velocity in short), and we express it as

$$\vec{v} = \lim_{\Delta t\to 0}\frac{\Delta\vec{r}}{\Delta t} = \frac{\mathrm{d}\vec{r}}{\mathrm{d}t} \tag{1.4a}$$

The vector $\vec{v}$ can also be written as

$$\vec{v} = \lim_{\Delta t \to 0}\left(\frac{\Delta x}{\Delta t}\vec{i} + \frac{\Delta y}{\Delta t}\vec{j} + \frac{\Delta z}{\Delta t}\vec{k}\right) = v_x\vec{i} + v_y\vec{j} + v_z\vec{k} \tag{1.4b}$$

where $v_x = \frac{dx}{dt}$, $v_y = \frac{dy}{dt}$, and $v_z = \frac{dz}{dt}$ are the components of the velocity $\vec{v}$ along the Ox, Oy, and Oz axes, they are also called the velocity components.

We term the absolute value of velocity, i. e., $|\vec{v}|$ or simply v, as speed. Because $|d\vec{r}| = ds$, we have

$$v = |\vec{v}| = \left|\frac{d\vec{r}}{dt}\right| = \frac{ds}{dt} \tag{1.5}$$

From Eq. 1.4b, we can also get

$$v = |\vec{v}| = \sqrt{v_x^2 + v_y^2 + v_z^2} \tag{1.6}$$

Speed is a scalar.

When a mass point executes a curvilinear movement, at some point of the curve the direction of the instantaneous velocity of the mass point is the direction of the tangent line of the curve at the point.

The SI unit of velocity and speed is m/s. (SI—International System, a system of units)

1.4 Acceleration

The velocity of a mass point may change in magnitude or direction as the mass point moves. The rate at which velocity changes is called acceleration. In symbols, average acceleration $\bar{\vec{a}}$ is defined to be

$$\bar{\vec{a}} = \frac{\Delta\vec{v}}{\Delta t} \tag{1.7}$$

where $\Delta\vec{v} = \vec{v}_{\text{final}} - \vec{v}_{\text{initial}}$ is the change in velocity. Average acceleration $\bar{\vec{a}}$ is also a vector. The direction of $\bar{\vec{a}}$ is the same as the direction of $\Delta\vec{v}$.

Instantaneous acceleration (called acceleration in short) $\vec{a}$ is the limit of the average acceleration as Δt approaches zero, and we express it as

$$\vec{a} = \lim_{\Delta t \to 0}\frac{\Delta\vec{v}}{\Delta t} = \frac{d\vec{v}}{dt} \tag{1.8a}$$

It can also be written as

$$\vec{a} = a_x\vec{i} + a_y\vec{j} + a_z\vec{k} \tag{1.8b}$$

where $a_x = \frac{dv_x}{dt}$, $a_y = \frac{dv_y}{dt}$, and $a_z = \frac{dv_z}{dt}$.

In general the direction of the acceleration has no relation to the direction of $\vec{v}$. It is possible for $\vec{v}$ and $\vec{a}$ to be parallel, perpendicular to each other, or at any other angle.

Because $\vec{v}$ is a vector, a change in its direction gives an acceleration, even if its magnitude is unchanged. Thus motion at constant speed can be accelerated motion.

The SI unit of acceleration is m/s^2.

If we know acceleration and initial velocity, we can get velocity by integral method.

Example 1.1 Let the equation of motion be $\vec{r}(t) = x(t)\vec{i} + y(t)\vec{j}$, where $x(t) = t + 2$, $y(t) = \frac{1}{2}t^2$, and the unit of t is second, the units of $\vec{r}$, x and y are meter. (a) Find the equation of the trajectory of the mass point. (b) What are the position vector, velocity vector and acceleration vector at $t = 2s$?

Solution (a) By eliminating t, the trajectory will be the relation between the coordinates x and y. Hence

$$y = \frac{1}{2}(x-2)^2$$

(b) At $t = 2s$, $x(2) = 4m$, $y(2) = 2m$

So the position vector is

$$\vec{r}(2) = (4\vec{i} + 2\vec{j})\,m$$

According to Eq. 1.4b, we get the velocity components

$$v_x(t) = \frac{dx}{dt} = 1 \qquad v_y(t) = \frac{dy}{dt} = t$$

At $t = 2s$, $v_x(2) = 1\,m/s$, $v_y(2) = 2\,m/s$. The velocity vector is therefore

$$\vec{v}(2) = (1\vec{i} + 2\vec{j})\,m/s$$

According to Eq. 1.8b, we get the components of the acceleration

$$a_x(t) = \frac{dv_x}{dt} = 0 \qquad a_y(t) = \frac{dv_y}{dt} = 1$$

At $t = 2s$, the acceleration is

$$\vec{a}(2) = 1\vec{j}\,m/s^2$$

Example 1.2 An object moves along a straight line from v_0 with $\frac{dv}{dt} = -kvt$ (k is a constant). What is the function of $v(t)$?

Solution $\frac{dv}{dt} = -kvt$ can be written as

$$\frac{dv}{v} = -kt\,dt$$

Take the integral of both sides of this equation

$$\int_{v_0}^{v} \frac{dv}{v} = -\int_0^t kt\,dt$$

Carrying out the integrals, we obtain

$$v = v_0 e^{-\frac{1}{2}kt^2}$$

1.5 One-Dimensional Motion

Now we deal with one-dimensional motion, that is, motion along a straight line. We usually designate vector quantities with arrows. But in one-dimensional motion, it will not be necessary to use the arrows. The reason is that in one-dimensional motion an object can only move in two directions, and these directions are easily specified by plus and minus signs.

In one-dimensional motion, the displacement can be written as

$$\Delta r = \Delta x \tag{1.9}$$

The average velocity can be written as

$$\bar{v} = \frac{\Delta x}{\Delta t} \tag{1.10}$$

The instantaneous velocity can be written as

$$v = \frac{dx}{dt} \tag{1.11}$$

The average acceleration can be written as

$$\bar{a} = \frac{\Delta v}{\Delta t} \tag{1.12}$$

The instantaneous acceleration can be written as

$$a = \frac{dv}{dt} \tag{1.13}$$

The direction of these each vector of the above can be represented simply by a plus or minus sign. A positive value indicates that the direction is in the positive x direction. Similarly, a negative value indicates that the direction is in the negative x direction.

The acceleration of a mass point can be viewed as constant if its value and direction do not change with time. The average acceleration equals the instantaneous acceleration when acceleration is constant. That is

$$\bar{a} = a = \text{constant}$$

Consider one-dimensional motion with constant acceleration. We start with the Eq. 1.13, which we can write as

$$dv = a dt$$

We take the integral of both sides of this equation

$$\int_{v_0}^{v} dv = \int_0^t a dt = a \int_0^t dt$$

where the last step, taking the acceleration out of the integral, can be made because the