（英文本）

大学物理解题指南

·力 学·

Solution Manual Of University Physics

·Mechanics·

〔中〕王义民　〔美〕克利夫顿·凯勒　托马斯·郑

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内 容 简 介

本书为英文版，是作者在总结大学物理教学经验的基础上，为提高学生在经典力学中分析问题的能力与解题技巧而编写的。它不采用通常教科书的编写方式，而是突出每章的重要物理概念、原理和定律，借助例题求解的形式，使读者掌握基本物理概念及物理定律的运用。

本书叙述通俗易懂，对于培养阅读与写作专业英语的能力很有裨益。

全书内容有质点运动学、静力学、质点动力学、功与能、刚体力学。汇集300余个例题。

本书可作为高等学校理工科大学生的参考书，对电大、函授大学等工科专业学生，高等学校教师和中学物理教师亦有参考价值，对想提高专业英语基础的工程技术人员也是一本值得一读的图书。

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浙江大学出版社出版

上虞汤浦印刷厂排版

三墩印刷厂印刷

浙江省新华书店发行

*　*　*

850×1168　32开本　13　印张　316千字

1988年3月　第一版　　1988年6月第一次印刷

印数：0001－5000

ISBN 7-308-00054-0

0·013[课]　　定价：2.55元

Preface

The University Physics is one of the important basic courses for the students of science and engineering. The students will get to know the fundamental structure and the interaction of matters, master the movement rules in the most elementary and general forms (mechanical, heat, electromagnetic motions, the motion of microcosmic particles etc.), and train the ability of analysing physical pnenomena and solving the problems of physics by learning this subject.

The textbooks, in general, put the primary emphasis on the first two goals above, and cannot do full justice to the task of exposing students to all varieties of practical problems. The authors' intention in producing this book has been to avoid the mentioned deficiency and let the students to get a real "feeling" of all the important laws and principles of physics. Four parts of physics——Mechanics, Heat and Molecular Physics, Electromagnetism, Optics and Quantum Physics——will be includeid in the series of books.

Mechanics is the study of mathematial models describing the relationships between the phenomena which are observed to cause bodies to move and the observed motions of those bodies. Only one type of mathematical models of motion will be described here, which is the classical model due to Newton, so it is called Newtonian mechanics or classical mechanics. Our *Mechanics* is just involved in this field.

Mechanics contains over 300 problems which are typical and valuable in different branches of classical mechanics. All the important concepts, principles and laws relevant to the subject stand at the beginning of each chapter. The analytic process and completed solution of these problems are given and further discussion to the results of some problems has been made. In this way the students could extend their understanding on the physical meanings of these results. All of the problems are calculated in SI units and in each chapter they have been carefully graded with the more difficult ones following the easier ones. Most of the problems have been clearly illustrated by the special designed diagrams.

We hope that the students will attain the following aims through learning the *Mechanics*.

1. To grasp the quantities of physics such as vector of position, displacement, velocity, acceleration, to master how to calculate the angular velocity and angular acceleration, tangential and normal acceleration while a particle moves along a circle, and to be able to analyse the problems of relative motion.

2. To solve the problems of statics generally by using the conditions of equilibrium of forces.

3. To master Newton's three laws of motion to solve the dynamical problems for a particle.

4. To understand how to calculate the work done by constant forces or variable forces, to grasp the features about the work done by conservative forces and therefore know how to calculate the potential energy, and to be able skillfully use the kinetic energy theorem, work-energy theorem, conservation law of momentum, etc.

5. To learn how to use rotation law with a fixed axis and conservation law of angular momentum to solve the dynamical problems for a rigid body.

All these aims are covered by five chapters in this book.

We want to thank our many colleagues and students who have contributed suggestions to the book. We are grateful to Prof. Quan Yongxin, F. D. Stacey, Melba Phillips, Robert T. Lee. Liew Fah-seng. We request all our readers to favour us with their valuable suggestions and comments for further improving the contents and quality of the book.

Hefei, CHINA Y.M.W.

Berrien Springs, USA C.K.

San Diego, USA T.T.

February 1988

CONTENTS

CHAPTER 1

KINEMATICS OF PARTICLES

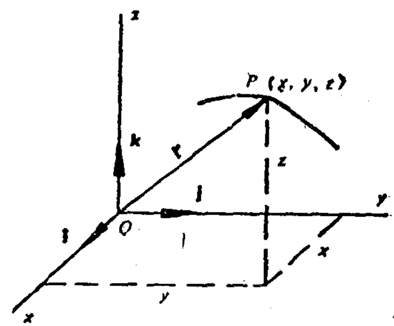
Important Concepts, Principles And Laws

A. Superposition Principle of Motions

The transfer of a particle from one place to another may be viewed as a simple displacement or as a superposition of several independent motions.

B. Equation of Motion

A particle's position P may be described by rectangular coordinates x, y and z or by a position vector r (Fig.). The position of a moving particle is a function of time t. The functional relations are called the equation of motion of a particle.



Figure

$$x = f_1(t),\quad y = f_2(t),\quad z = f_3(t)$$

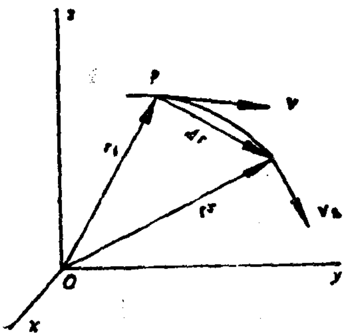
and
$$\mathbf{r} = \mathbf{r}(t)$$

or
$$r = xi + yj + zk$$

where i, j and k are unit vectors along the x-, y- and z- axes respectively.

C. Displacement Δr (or change in a particle's position)

Let the position vector of a particle be r_1 at instant t_1 and r_2 at instant t_2 (Fig.). The displacement $\Delta \mathbf{r}$ of the particle in time interval $\Delta t = t_2 - t_1$ is the vector difference



Figure

of r_2 and r_1.

$$\Delta r = r_2 - r_1$$

or $$\Delta r = \Delta x i + \Delta y j + \Delta z k$$

where Δx, Δy, Δz are x-, y- and z- components of vector displacement Δr respectively.

D. **Average Velocity $\bar{v}$**

Average velocity is defined as displacement divided by the time interval during which this displacement is covered.

$$\bar{v} = \frac{\Delta r}{\Delta t}$$

E. **Instantaneous Velocity v** (or simply velocity)

The velocity of a particle is defined as the limiting value of the average velocity as the time interval approaches zero.

$$v = \lim_{\Delta t \to 0} \bar{v} = \lim_{\Delta t \to 0} \frac{\Delta r}{\Delta t} = \frac{dr}{dt}$$

or $$v = \frac{dx}{dt} i + \frac{dy}{dt} j + \frac{dz}{dt} k = v_x i + v_z j + v_y k$$

where v_x, v_y, and v_z are $x-$, $y-$, and $z-$components of velocity v respectively.

F. **Average Acceleration $\bar{a}$**

This vector acceleration is defined as the ratio of the change in velocity ($\Delta v = v_2 - v_1$) to the elapsed time.

$$\bar{\mathbf{a}} = \frac{\Delta \mathbf{v}}{\Delta t}$$

G. **Instantaneous Acceleration** $\mathbf{a}$, commonly called acceleration:

The acceleration of a particle is defined as the limiting value of the average acceleration as the elapsed time approaches zero.

$$\mathbf{a} = \lim_{\Delta t \to 0} \bar{\mathbf{a}} = \lim_{\Delta t \to 0} \frac{\Delta \mathbf{v}}{\Delta t} = \frac{d\mathbf{v}}{dt}$$

or

$$\mathbf{a} = \frac{d^2x}{dt^2}\mathbf{i} + \frac{d^2y}{dt^2}\mathbf{j} + \frac{d^2z}{dt^2}\mathbf{k}$$

$$= \frac{dv_x}{dt}\mathbf{i} + \frac{dv_y}{dt}\mathbf{j} + \frac{dv_z}{dt}\mathbf{k}$$

$$= a_x\mathbf{i} + a_y\mathbf{j} + a_z\mathbf{k}$$

Where a_x, a_y, and a_z are x-, y-, and z-components of acceleration $\mathbf{a}$ respectively.

H. **Normal Acceleration $\mathbf{a}_n$ and Tangential Acceleration $\mathbf{a}_t$**

In a curved motion the change rate of direction of a particle's velocity is measured by normal acceleration $\mathbf{a}_n$, and the change rate of speed of a particle is measured by tangential acceleration $\mathbf{a}_t$. Their magnitudes are respectively

$$a_n = \frac{v^2}{\rho}, \qquad a_t = \frac{dv}{dt}$$

where ρ is the radius of curvature. The resultant acceleration in curved motion is

$$\mathbf{a} = \mathbf{a}_n + \mathbf{a}_t$$

$$a = \sqrt{a_n^2 + a_t^2}, \qquad \tan\phi = \frac{a_t}{a_n}$$

where ϕ shows the direction of the resultant acceleration.

In the case of circular motion, the radius of curvature ρ becomes radius R of the circle, and a_n is called centripetal acceleration.

I. Angular Displacement θ, Angular Velocity ω, and Angular Acceleration α

The circular motion of a particle or the rotation of a rigid body are described by angular displacement θ, angular velocity ω, and angular acceleration α. Angular displacement θ is defined as the sweeping angle in time t by a rotating radius R or a linking line from the moving particle to rotating center, when the unit of angle is radians,

$$\theta=\frac{s}{R}$$

where s is the length of an arc.

The angular velocity is defined as the limiting value of the angular displacement as the elapsed time approaches zero,

$$\omega=\frac{d\theta}{dt}$$

The unit of angular velocity is one radian per second, simply $1s^{-1}$.

The angular acceleration is defined as the limiting value of the change of angular velocity as the elapsed time approaches zero,

$$\alpha=\frac{d\omega}{dt}$$

The unit of angular acceleration is $1\ rad\cdot s^{-2}$ or $1\ s^{-2}$.

The relations between angular and linear quantities are

$$v = \omega R, \qquad a_t = \alpha R$$

Where R is the rotating radius.

J. Relative Motion

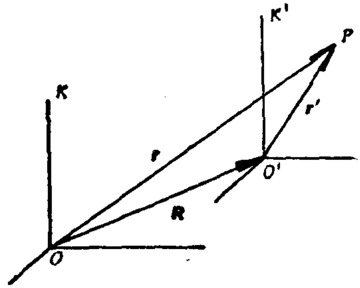
Let there be a resting frame K fixed on the earth, and a moving frame K' with respect to the earth. If the vector positions of a moving particle P relative to the origins of the frames K and K' are $\boldsymbol{r}$ and $\boldsymbol{r}'$ respecitvely at an instant and the vector position of the two frames' origins is $\boldsymbol{R}$, then as shown in the Fig.

$$\boldsymbol{r} = \boldsymbol{r}' + \boldsymbol{R}$$

We take first derivative of above equation with respect to time t, get

$$\boldsymbol{v} = \boldsymbol{v}' + \boldsymbol{V}$$

where $\boldsymbol{v}$ is called the absolute velocity of the particle, $\boldsymbol{v}'$ is called the relative velocity and $\boldsymbol{V}$ is called the velocity of following.



Figure

We take the second derivative of the equation with respect to t, get

$$\boldsymbol{a} = \boldsymbol{a}' + \boldsymbol{A}$$

Where $\boldsymbol{a}$, $\boldsymbol{a}'$ and $\boldsymbol{A}$ are called the particle's absolute acceleration, relative acceleration and the acceleration of following respectively.

K. Vector Operations

Let two vectors $\boldsymbol{A}$ and $\boldsymbol{B}$ have the following coordinate expressions:

$$\boldsymbol{A} = A_x\boldsymbol{i} + A_y\boldsymbol{j} + A_z\boldsymbol{k}$$

$$\boldsymbol{B} = B_x\boldsymbol{i} + B_y\boldsymbol{j} + B_z\boldsymbol{k}$$

The addition and difference of the two vectors are as follows:

$$\boldsymbol{A} \pm \boldsymbol{B} = (A_x \pm B_x)\boldsymbol{i} + (A_y \pm B_y)\boldsymbol{j} + (A_z \pm B_z)\boldsymbol{k}$$

The scalar product of the two vectors is

$$\boldsymbol{A} \cdot \boldsymbol{B} = AB\cos\theta$$

where θ is the angle between $\boldsymbol{A}$ and $\boldsymbol{B}$. Alternately the scalar product can be expressed as

$$\begin{aligned}\boldsymbol{A} \cdot \boldsymbol{B} &= (A_x\boldsymbol{i} + A_y\boldsymbol{j} + A_z\boldsymbol{k}) \cdot (B_x\boldsymbol{i} + B_y\boldsymbol{j} + B_z\boldsymbol{k}) \\ &= A_xB_x + A_yB_y + A_zB_z\end{aligned}$$

The vector product of the two vectors is

$$\boldsymbol{A} \times \boldsymbol{B} = \boldsymbol{C}$$

The magnitude of $\boldsymbol{C}$ is defined by

$$C = AB\sin\theta$$

Where θ is the smaller angle between $\boldsymbol{A}$ and $\boldsymbol{B}$. The direction of $\boldsymbol{C}$ is defined to be perpendicular to the plane formed by $\boldsymbol{A}$ and $\boldsymbol{B}$ and determined by the rule of right-hand-thread screw.

The vector product is also expressed as follows:

$$\boldsymbol{A} \times \boldsymbol{B} = (A_yB_z - A_zB_y)\boldsymbol{i} + (A_zB_x - A_xB_z)\boldsymbol{j} + (A_xB_y - A_yB_x)\boldsymbol{k}$$

or

$$\boldsymbol{A} \times \boldsymbol{B} = \begin{vmatrix} \boldsymbol{i} & \boldsymbol{j} & \boldsymbol{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

1-1 Given three vectors

$\boldsymbol{A} = 4\boldsymbol{i} + 3\boldsymbol{j} - \boldsymbol{k}$, $\boldsymbol{B} = 3\boldsymbol{i} - \boldsymbol{j} + \boldsymbol{k}$, $\boldsymbol{C} = 2\boldsymbol{i} - 3\boldsymbol{j}$.

Find:

1) $\boldsymbol{A} + \boldsymbol{B}$ 2) $\boldsymbol{A} - \boldsymbol{B}$ 3) $A_x + B_y - C_z$ 4) $\boldsymbol{A} \cdot \boldsymbol{i}$

5) $A\cdot C$ 6) $(A\cdot C)B-(A\cdot B)C$ 7) $A\times B$

8) $A\times B\times C$

Answers:

1) $7i+2j$ 2) $i+4j-2k$ 3) 3 4) 4 5) -1

6) $-19i+25j-k$ 7) $2i-7j-13k$ 8) $-39i-26j+8k$

1-2 The vector displacements of two particles emitted from a point at the same time are

$r_1=4i-2j+9k$ and $r_2=2i+9j+4k$

1) Plot these vectors and write the displacement of the second particle relative to the first.

2) Find the values of r_1, r_2 and Δr

3) Find the three angles of the triangle formed by these three vectors.

Solution:

1) $\Delta r=r_2-r_1=2i+9j+4k-(4i-2j+9k)=-2i+11j-5k$ and see the Fig. 1-1.

2) $r_1=\sqrt{4^2+2^2+9^2}$

$=\sqrt{101}=10.05\text{ m}$

$r_2=\sqrt{2^2+9^2+4^2}$

$=\sqrt{101}=10.05\text{ m}$

$\Delta r=\sqrt{2^2+11^2+5^2}$

$=\sqrt{150}=12.25\text{ m}$

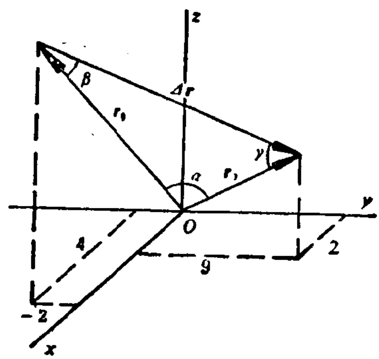


Figure 1-1

3) Let the three angles are α、β and γ, see Fig. 1-1. Since $(\Delta r)^2=r_1^2+r_2^2-2r_1r_2\cos\alpha$, hence

$$\cos\alpha=\frac{r_1^2+r_2^2-(\Delta r)^2}{2r_1r_2}=\frac{101+101-150}{2(10.05)^2}=0.26$$

$\therefore \qquad \alpha = 75.4°$

and since $r_1 = r_2$, therefore

$$\beta = \gamma = \frac{180° - \alpha}{2} = \frac{180° - 75.4°}{2} = 52.3°$$

1-3 In a coordinate system, the position vector of a thrown baseball is given by

$$r = 1.2i - 8tj + (6t - 4.9t^2)k$$

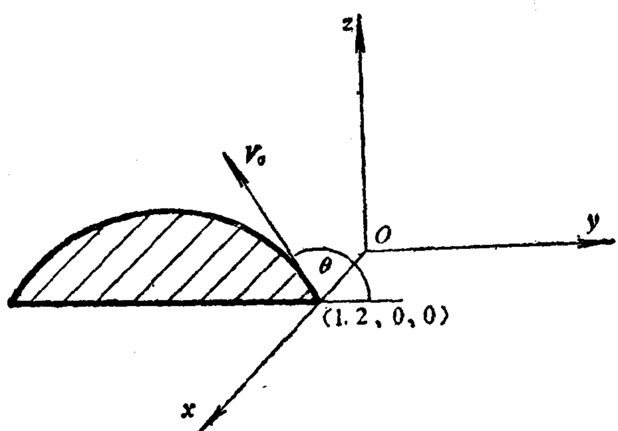


Figure 1-2

1) Find the baseball's coordinates at $t = 0$.

2) Find the ball's initial velocity and its velocity at any other instant.

3) What is the ball's acceleration?

4) Draw the trajectory of the ball.

Solution:

a) When $t = 0$, $r = 1.2i$m. The coordinates of the ball's initial position is (1.2, 0, 0).

b) $v = \frac{dr}{dt} = -8j + (6 - 9.8t)k \ \text{m·s}^{-1}$. This shows the ball's plane of motion parallel to the yz plane.

When $t=0, \mathbf{v}_0=-8j+6k$

$$v_0=\sqrt{v_{0y}^2+v_{0z}^2}=\sqrt{(-8)^2+6^2}=10\text{m}\cdot\text{s}^{-1}$$

$$\theta=\arctan\frac{v_{0z}}{v_{0y}}=\arctan\left[-\frac{6}{8}\right]=143°08'$$

where θ is the angle between the initial velocity vector $\mathbf{v}_0$ and the y axis.

c) The ball's acceleration is found by differentiation.

$$\mathbf{a}=\frac{d\mathbf{v}}{dt}$$

$$=\frac{d}{dt}[-8j+(6-9.8t)k]$$

$=-9.8k$, i.e. $-9.8\ \text{m}\cdot\text{s}^{-2}$ is the constant of acceleration.

d) The ball's trajectory is a parabola (Fig. 1-2).

1-4 A particle has the following equation of motion

$$y=6\times10^{-2}\ \sin\frac{\pi}{3}t\ \text{m}$$

1) Sketch graphs of position, velocity, and acceleration of the particle as functions of time t.

2) Find the values of y, v and a when $t=1.0$ s.

3) Find time, velocity and acceleration at $y=3\times10^{-2}$m.

4) In what position does the particle have maximum elocvity and acceleration?

Solution:

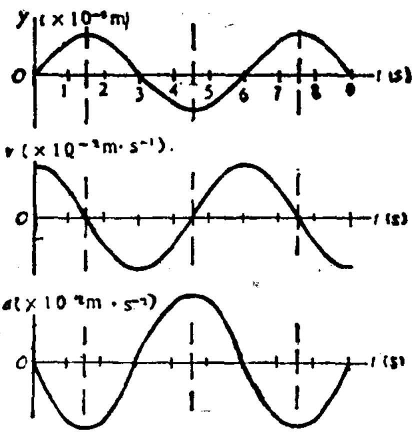
1) The equations of y, v and a are functions of t and expressed as follows:

$$y=6\times10^{-2}\ \sin\frac{\pi}{3}t \tag{1}$$

$$v = \frac{dy}{dt} = 6\times10^{-2}\left[\frac{\pi}{3}\right]\cos\frac{\pi}{3}\ t = 2\pi\times10^{-2}\cos\frac{\pi}{3}t \quad (2)$$

$$a = \frac{dv}{dt} = -\frac{2}{3}\pi^2\times10^{-2}\ \sin\frac{\pi}{3}t \quad (3)$$

We can sketch the required graphs, according to equations (1), (2) and (3). (See Fig. 1-3)



Eigure.1-3

2) When $t = 1.0$ s, the above equations become

$$y_1 = 6\times10^{-2}\ \sin\frac{\pi}{3} = 5.20\times10^{-2}\ \text{m}$$

$$v_1 = 2\pi\times10^{-2}\cos\frac{\pi}{3} = 3.14\times10^{-2}\ \text{m}\cdot\text{s}^{-1}$$

$$a_1 = -\frac{2}{3}\pi^2\times10^{-2}\ \sin\frac{\pi}{3} = -5.70\times10^{-2}\ \text{m}\cdot\text{s}^{-2}$$

3) From equation (1) at $y = 3\times10^{-2}$m, we have

$$\sin\frac{\pi}{3}t = \frac{3\times10^{-2}}{6\times10^{-2}} = \frac{1}{2}$$