Textbook Series for 21st Century

PHYSICS

Fifth Edition Part II

AUTHORS MA WENWEI / XIE XISHUN / ZHOU YUQING

TRANSLATORS ZHU MING / XU WENXUAN

HIGHER EDUCATION PRESS

Textbook Series for 21st Century

PHYSICS

Fifth Edition Part II

AUTHORS MA WENWEI / XIE XISHUN / ZHOU YUQING

TRANSLATORS ZHU MING / XU WENXUAN

HIGHER EDUCATION PRESS

INTRODUCTION OF CONTENT

On the base of *Physic*(Fourth Edition), the revision of this book is made consulting *The Basic Requirement of Teaching University Physics Course for Non-physical Major in University of Science and Engineering* (*Discussion Draft*) and constituted lastly by sub-committee of physics essential lecture teaching guidance for non-physics specialty, Education Department. What in the book contains all of kernels required in the basic requirement, moreover, a certain amount of extension content is presented as well as for different majors. In the revision, this book keeps specialties such as logical system, well-situated profundity and extension, proper capacity, wide flexibility coming from the original vision of the book. Meanwhile, it adds more contents in following aspects: modern physics, the annotation with modern viewpoints for classic physics, and the effects to science and technology from the achievements of modern physics.

This book has two volumes. In Volume Ⅰ, it contains mechanics and electromagnetic. And in Volume Ⅱ, it contains oscillation and undulation, optics, theory of molecular dynamics and basic of thermodynamics, theory of relativity, quantum physics. There are books *The Applications of Physical Principle in Engineering and Technology*(Third Edition), *The Analysis and Solution for Exercises in Physics*(Fifth Edition), *Guidance for Learning Physics*(Fifth Edition) and the multimedia *The Electronic Teaching Plan for Physics* (Fifth Edition) to form a complete set with this book.

This book can be the teaching material of the higher education for non-physical major in university of sciences and engineering. It can also be selected as texts by the relevant fields of social sciences and natural sciences and read by social readers at large.

图书在版编目(CIP)数据

物理学：第5版.下册：英文/马文蔚，解希顺，周雨青编；朱明，徐文轩译.—北京：高等教育出版社，2009.7
ISBN 978-7-04-027263-5

Ⅰ.物…　Ⅱ.①马…②解…③周…④朱…⑤徐…　Ⅲ.物理学-双语教学-高等学校-教材-英文　Ⅳ.04

中国版本图书馆CIP数据核字(2009)第088916号

策划编辑　郭亚嫘　**责任编辑**　郭亚嫘　**封面设计**　王凌波　**责任绘图**　尹　莉
版式设计　王艳红　**责任校对**　杨雪莲　**责任印制**　毛斯璐

出版发行	高等教育出版社	**购书热线**	010-58581118
社　　址	北京市西城区德外大街4号	**免费咨询**	800-810-0598
邮政编码	100120	**网　　址**	http://www.hep.edu.cn
总　　机	010-58581000		http://www.hep.com.cn
		网上订购	http://www.landraco.com
经　　销	蓝色畅想图书发行有限公司		http://www.landraco.com.cn
印　　刷	国防工业出版社印刷厂	**畅想教育**	http://www.widedu.com
开　　本	850×1168　1/16	**版　　次**	2009年7月第1版
印　　张	24.5	**印　　次**	2009年7月第1次印刷
字　　数	740 000	**定　　价**	31.80元

物料号　27263-00

The Quantity and Unit in the Fluctuations Process, Thermal Physics and Modern Physics

Quantity		Units	
Name	Symbol	Name	Symbol
cycle	T	second	s
frequency	$f(\nu)$	hertz	Hz
angular frequency	ω	radian per second	$rad \cdot s^{-1}$
wavelength	λ	meter	m
angle wave number	k	per meter	m^{-1}
the speed of light	c	meters per second	$m \cdot s^{-1}$
vibration displacement	x, y	meter	m
vibration velocity	v	meter per second	$m \cdot s^{-1}$
sound Intensity	I	watt per square meter	$W \cdot s^{-2}$
pressure	p	pascal	Pa
volume	V	cubic meters	m^3
		liter	L(l)
thermodynamic temperature	T	kelvin	K
celsius temperature	t	degrees	°C
amount of substance	ν, n	mole	mol
molar mass	M	1 000 grams per mole	$kg \cdot mol^{-1}$
molecular free path	λ	meter	m

(Be continued)

Quantity		Units	
Name	Symbol	Name	Symbol
molecule collision frequency	Z	times per second	s^{-1}
viscosity	η	kilograms per meter second	$kg \cdot m^{-1} \cdot s^{-1}$
thermal conductivity	κ	watts per meter kelvin	$W \cdot m^{-1} \cdot K^{-1}$
diffusion coefficient	D	square meters per second	$m^2 \cdot s^{-1}$
specific heat capacity	c	joule per kilogram kelvin	$J \cdot kg^{-1} \cdot K^{-1}$
molar heat capacity	$C_m, C_{V,m}, C_{p,m}$	joule per mole kelvin	$J \cdot mol^{-1} \cdot K^{-1}$
molar heat capacity ratio	$\gamma = C_{p,m}/C_{V,m}$	—	1
heat engine efficiency	η	—	1
refrigeration coefficient	e	—	1
entropy	S	joule per kelvin	$J \cdot K^{-1}$
radiation intensity	I	watt per square meter	$W \cdot m^{-2}$
radiant energy density	$w(u)$	joule per cubic meter	$J \cdot m^{-3}$
atomic number	Z	—	1
neutron number	N	—	1
nuclear number	A	—	1
electronics static quality	m_e	kilogram	kg
proton static quality	m_p	kilogram	kg
neutron static quality	m_n	kilogram	kg
initial charge	e	coulomb	C
planck constant	h	joule second	$J \cdot s$
bohr radius	r_b	meter	m

(Be continued)

Quantity		Units	
Name	Symbol	Name	Symbol
rydberg constant	R	per meter	m^{-1}
orbital quantum number of angular momentum	l	—	1
spin magnetic quantum number of angular momentum	m_s	—	1
principal quantum number	n	—	1
orbital magnetic quantum number of angular momentum	m_l	—	1
wave function	ψ	—	1

Table of Content

9

Chapter Oscillation

The oscillation we normally study is a periodical motion. The so called periodical motion is a motion that has repetitiveness and reciprocating properties in time. It is a common motion in the world of nature and science, like the motion of planets, the cycle of blood, the cycle of ecosystem, the vibration of consumption exponent and more. If a periodical motion is only the back–and-forth motion of the position then we call it mechanical vibration. The heart beating, the swinging pendulum of a grandfather clock, the back – and – forth motion of the pistons in a car engine, atoms vibrate within a molecule – all these are examples of mechanical vibration. In physics, generally speaking, when physical quantities that describe the motion state of object vary in period near a certain value, we say they undergo vibration. For example, a current in an AC circuit varies in period around a certain value; when light wave and radio wave propagate in space, both electric field intensity and magnetic field intensity vary in period, all these vibration are called electromagnetic vibration. Although electromagnetic vibration is different with mechanical vibration in nature, many of the descriptions about them are the same. Therefore, the basic principle of mechanical vibration is also the essence to study other vibration and wave motion, such as wave optics, radio technique and so on. Mechanical vibration has widely use in production and technology.

In this chapter we will study simple harmonic motion and briefly introduce damped oscillation, forced oscillation, resonance, electromagnetic vibration and more.

9 - 1 Simple Harmonic Motion, Amplitude, Period and Frequency, Phase

1. Simple harmonic motion

There are many forms of vibration and situations are complicated. If oscillation can be expressed by a single function of time, i. e., the cosine or sine function, then it is called the simple harmonic motion. Simple harmonic motion is the simplest and basic oscillation. Next we will start from an object oscillating on the end of a coil spring to study the regulation of simple harmonic motion.

As shown in Fig. 9 - 1, a spring ignoring its weight, an object with mass m is attached on one end of the spring while the other end is fixed, is put on a frictionless horizontal plane. At the beginning the object is at the position O, the spring has its nature length [Fig. 9 - 1 (a)] and at this moment in horizontal direction the combined external force on the object equals zero. The position O of the object at this point is called the **equilibrium position**. Choose the equilibrium position as the origin and the horizontal rightward direction is the positive direction of Ox axis. An external force pulls the object to the left [Fig. 9 - 1 (b)]. At this moment because of the spring being stretched, it exerts an elastic force on the object that acts in the direction of returning the object to the equilibrium position. After the external force is withdrew, under the elastic force the object moves to left. When the object passes the equilibrium position the elastic force decreases to zero, but the object still keeps moving to left because of the inertia and makes the spring compressed. Since the compressed spring exerts the object rightward elastic force to resist it moving, the speed of the object decreases. When the object reaches point C the speed decreases to zero [Fig. 9 - 1 (c)] and again under the elastic force the object moves from C to right. Therefore, under elastic force the object goes into a back and forth motion on both side of the equilibrium position. The oscillation system including the spring and the object is called **the spring oscillator**.

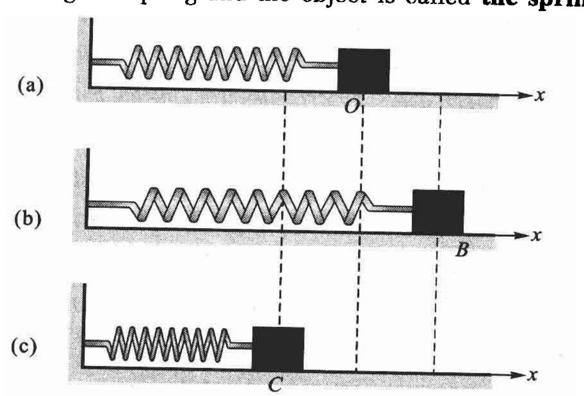

Figure 9 - 1 The oscillation of a spring oscillator

According to Hooke ' s law, the elastic force that the object subjected is directly proportional to the displacement x to the equilibrium position. Whenever the object is displaced from its equilibrium position, the spring force tends to restore it to the equilibrium position. We called a force with this character a restoring force. Therefore, we have

$$F = -kx$$

where the ratio constant is spring constant, it depends on the properties of the spring itself (material, shape and size) , the negative sign indicates that the direction of the force is opposite to the direction of the displacement.

According to Newton's second law, the acceleration of the object is

$$a = \frac{F}{m} = -\frac{k}{m}x \qquad (9-1)$$

For a certain spring oscillator, both m and k are constant and positive, their ratio can be expressed by a square of another constant ω, i. e,

$$\frac{k}{m} = \omega^2 \qquad (9-2)$$

Therefore, Eq. (9 - 1) can be written as

$$a = -\omega^2 x \qquad (9-3)$$

The equation above indicates that **the acceleration of the spring oscillator is proportional to the magnitude of the displacement and has opposite direction to the displacement.** People call such oscillation with this characteristic **simple harmonic motion.**

Eq. (9 - 3) can also be written as

$$\frac{d^2x}{dt^2} = -\omega^2 x \qquad (9-4)$$

This is the differential equation of the simple harmonic motion. Its solution is

$$x = A\cos(\omega t + \varphi) \qquad (9-5)$$

It is the motion function of the simple harmonic motion①, simple harmonic motion equation in short. Where A and φ are the integral constants, their physical meaning will be discussed later. From the equation above we can find, when an object in the simple harmonic motion, its displacement is a cosine function of time②. This is why we call the oscillation, whose motion equation has the form of Eq. (9 - 3) ~ (9 - 5), simple harmonic motion.

If we take the first and the second derivative of Eq. (9 - 5) with respect to time, the velocity and the acceleration of the object in simple harmonic motion are

$$v = \frac{dx}{dt} = -\omega A\sin(\omega t + \omega) \qquad (9-6)$$

$$a = \frac{d^2x}{dt^2} = -\omega^2 A\cos(\omega t + \omega) \qquad (9-7)$$

From Eq. (9 - 5), (9 - 6) and (9 - 7), it can produce the $x-t$, $v-t$ and $a-t$ figures shown in Fig. 9 - 2. From the figure we can conclude, when an object is in simple harmonic motion, its displacement, velocity, and acceleration changes periodically.

Now let us discuss the physical quantities A, ω and $(\omega t + \varphi)$ in Eq. (9 - 5), which has the characteristic of simple harmonic motion. We are also going to discuss other concepts, such as amplitude, period (frequency, angular frequency) and phase (initial phase), among them the concept of phase is extremely important.

---

① The motion equation of simple harmonic motion is also called simple harmonic motion in short.

② Since $\cos(\omega t + \varphi) = \sin(\omega t + \varphi + \pi/2)$, if $\varphi' = \varphi + \pi/2$ then Eq. (9 - 5) can be written as

$$x = A\sin(\omega t + \varphi')$$

Therefore, we can also say, if an object is in simple harmonic motion, the displacement is a sine function with respect of time. Either cosine function or sine function is simple harmonic function. In order to maintain unity, we use cosine function in this textbook.

2. Amplitude

In the simple harmonic motion function $x = A\cos(\omega t + \varphi)$, since the value of $\cos(\omega t + \varphi)$ is between +1 and −1, therefore, the displacement of the object is between $+A$ and $-A$. We call **the absolute value A of the maximum position of the object relative to its equilibrium position the amplitude.**

3. Period and frequency

The time that the object takes to finish one complete cycle of motion is called the period of vibration, denotes by T, the unit of period is s. In Fig 9 − 1, the object starts at point B, passing O, to reach point C, and then return to point B, the time takes to complete this motion is called one period. Therefore, the displacement and the velocity of the object at any moment t must be the same as the displacement and the velocity at the moment $t + T$. So we have

$$x = A\cos(\omega t + \varphi) = A\cos[\omega(t + T) + \varphi] = A\cos(\omega t + \varphi + \omega T)$$

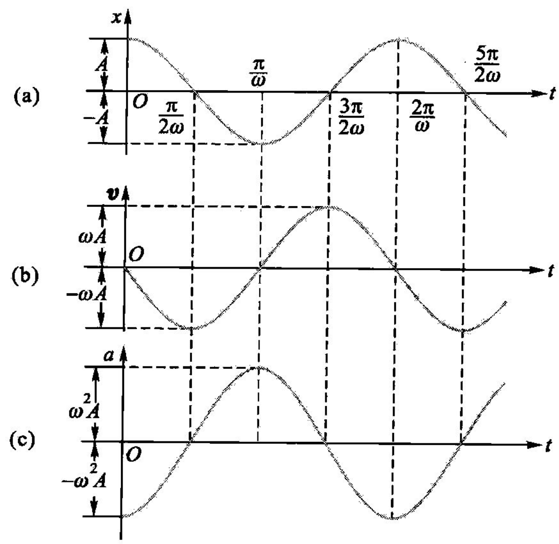

Figure 9 − 2 The graphic method of simple harmonic motion ($\varphi = 0$)

Because of the periodical character of cosine function, after the object finishes one complete oscillation $\omega T = 2\pi$. Therefore,

$$T = \frac{2\pi}{\omega} \tag{9-8}$$

From $\omega = \sqrt{k/m}$, the period of the spring oscillator is

$$T = 2\pi\sqrt{\frac{m}{k}} \tag{9-9}$$

The number of complete cycles or vibrations per unit of time is called the frequency, denotes by ν, its unit is Hertz (Hz). Obviously, the relationship between the frequency and the period is

$$\nu = \frac{1}{T} = \frac{\omega}{2\pi} \tag{9-10}$$

From the equation we can derive

$$\omega = 2\pi\nu \tag{9-11}$$