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大学预科物理

COLLEGE PREPARATORY PHYSICS

俞笑竹
（Yu Xiaozhu）

主编

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主编
俞笑竹
(Yu Xiaozhu)

副主编
许伯强

参编
戴海浪 冯 伟 帅学敏 许丹华

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PREFACE

In recent years, with the implementation of the "One Belt One Road" initiative and the international recognition of the strength of China's high education, the number of foreign students, especially those from countries along the "One Belt One Road" routes has shown an explosive growth. The foreign student education has become an important part of China's high education. In order to guarantee the quality of foreign students. Jiangsu University started the preparatory education for foreign students in 2014, according to the spirit and requirements of "notice"* announced by the Ministry of Education.

Physics is a compulsory course for preparatory students who are going to enter Chinese universities studying science, engineering, agriculture and medicine. This textbook, prepared by Science Faculty and Overseas Education College of Jiangsu University, is compiled for foreign students of the above majors. This textbook, covering most of the contents of senior high school physics, is reorganized based on teaching notes of five years preparatory physics course, and simplified under the requirements of college physics. This textbook is prepared for foreign students in order to strengthen their basis

* 《教育部关于对中国政府奖学金本科来华留学生开展预科教育的通知》"(The Ministry of Education) Notice about Developing Preparatory Education for Undergraduate Foreign Students under the Chinese Government Scholarship Program"

of physics and build a bridge to college physics study and future specialized courses.

This textbook contains three parts: mechanics, electromagnetism and optics. Considering that foreign students have graduated from high schools in their countries with a physical background, this textbook focuses on the following two aspects: One is to highlight the knowledge context in content, and the other is to link up with the teaching content of college physics. For these purposes and limited class hours, the teaching contents have been reduced by cutting thermology section and some other parts with little connection with college physics. The first to sixth chapters of mechanics section, the eighth to eleventh chapters of electromagnetics, and the thirteenth chapter of the optics are written by Yu Xiaozhu (Department of Physics, Jiangsu University). The seventh chapter of mechanics is written by Dai Hailang (Department of Physics, Jiangsu University). The twelfth chapter of optics is written by Feng Wei (Department of College Physics Teaching, Jiangsu University). The book is organized and proofread by Yu Xiaozhu.

This textbook can be used as a preparatory teaching material or a self-taught material for foreign students majored in science, engineering, agriculture and medicine in China.

Due to limited knowledge and time, mistakes and careless omissions in this article are unavoidable. Comments and suggestions are most welcome!

Finally, may all the foreign students make progress in their studies!

Editor

CONTENTS

CHAPTER 1 INTRODUCTION

Physics is an experimental science. Physicists observe the phenomena of nature and try to find patterns and principles that relate to these phenomena. These patterns are called physical theories or, when they are very well established and of broad use, physical laws or principles.

The study of physics is important because physics is one of the most fundamental sciences. Scientists of all disciplines make use of the ideas of physics, including chemists who study the structure of molecules, paleontologists who try to reconstruct how dinosaurs walked, and climatologists who study how human activities affect the atmosphere and oceans. Physics is also the foundation of all engineering and technology. No engineer could design a flat-screen TV, an interplanetary spacecraft, or even a better mousetrap without first understanding the basic laws of physics.

The study of physics is also an adventure. You will find it challenging, sometimes frustrating, occasionally painful, and often richly rewarding and satisfying. It will appeal to your sense of beauty as well as to your rational intelligence. If you've ever wondered why the sky is blue, how radio waves can travel through empty space, or how a satellite stays in orbit, you can find the answers by using fundamental physics. Above all, you will come to see physics as a towering achievement of the human intellect in its quest to understand our world and ourselves.

1.1 Unit Systems

A physical quantity is a physical property of a phenomenon, body, or substance, that can be quantified by measurement. For example, length, temperature, distance and time are physical quantities.

A physical quantity can be expressed as the combination of a magnitude expressed by a number—usually a real number—and a unit. For example, $1.674\ 927\ 5 \times 10^{-27}$ kg (the mass of the neutron) or 299 792 458 $m \cdot s^{-1}$ (the speed of light).

1.1.1 SI Units

SI Units

The name "SI units" comes from the French Système International d Unités, which means international system of units.

There are seven fundamental SI Units as listed in Table 1.1. These seven units are called fundamental units because none of them can be expressed as combinations of the other six.

Table 1.1 SI Fundamental Units

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

All other units we used in physics are combinations of these seven fundamental units. To make working with units easier, some combinations of the fundamental units are given special names, but it is always correct to reduce everything to the fundamental units. Table 1.2 lists some examples of combinations of SI fundamental units that are assigned with special names.

Table 1.2 Examples of combinations of SI fundamental units assigned special names

Physical Quantity	Unit Expressed in Fundamental Units	Name of Combination
Force	$kg \cdot m \cdot s^{-2}$	N (newton)
Frequency	s^{-1}	Hz (hertz)
Work	$kg \cdot m^2 \cdot s^{-2}$	J (joule)

1.1.2 Prefixes of Fundamental Units

Once we have defined the fundamental units, it is easy to introduce larger and

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smaller units for the same physical quantities. In the metric system these other units are related to the fundamental units by multiples of 10 or $\frac{1}{10}$.

The names of the additional units are derived by adding a prefix to the name of the fundamental unit. Table 1. 3 lists some of these prefixes. The case of the prefix symbol is very important. Where a letter features twice in the table, it is written in uppercase for exponents bigger than one and in lowercase for exponents less than one. For example M means mega (10^6) and means milli 10^{-3}.

Table 1. 3 Unit Prefixes

Prefix(abbreviation)	Power of Ten	Prefix(abbreviation)	Power of Ten
peta－(P)	10^{15}	deci－(d)	10^{-1}
tera－(T)	10^{12}	centi－(c)	10^{-2}
giga－(G)	10^{9}	milli－(m)	10^{-3}
mega－(M)	10^{6}	micro－(μ)	10^{-6}
kilo－(k)	10^{3}	nano－(n)	10^{-9}
		pico－(p)	10^{-12}
		femto－(f)	10^{-15}

Here are several examples of the use of multiples of 10 or $\frac{1}{10}$ and their prefixes with the units of length, mass, and time(Table 1.4).

Table 1. 4 Different units of length, mass and time

Length	1 nanometer = 1 nm = 10^{-9} m 1 micrometer = 1 μm = 10^{-6} m 1 millimeter = 1 mm = 10^{-3} m 1 centimeter = 1 cm = 10^{-2} m 1 kilometer = 1 km = 10^{3} m
Mass	1 microgram = 1 μg = 10^{-6} g = 10^{-9} kg 1 milligram = 1 mg = 10^{-3} g = 10^{-6} kg 1 gram = 1 g = 10^{-3} kg
Time	1 nanosecond = 1 ns = 10^{-9} s 1 microsecond = 1 μs = 10^{-6} s 1 millisecond = 1 ms = 10^{-3} s

1. 1. 3 Unit Consistency and Conversions

If the statement of a problem includes a mixture of different units, the units must be converted to a single, consistent set before the problem is solved. Quantities to be added or subtracted must be expressed in the same units. Usually the best way is to convert everything to SI Units.

Always write the numbers with the correct units and carry the units through the calculation. This provides a very useful check for calculations. If at some stage in a calculation you find that an equation or an expression has inconsistent units, you know you have made an error somewhere. In this book we will always carry units through all calculations, and we strongly urge you to follow this practice when you solve problems.

1.2 Scientific Notation and Significant Figures

1.2.1 Scientific Notation

In Science, one often needs to work with very large or very small numbers. These numbers can be written more easily in scientific notation.

Scientific Notation

In scientific notation, any number is written as the product of a number between 1 and 10 and an integer power of ten.

$$d \times 10^n$$

Where the ponent n is an integer.

If $n>0$, it represents how many times the decimal place in d should be moved to the right. If $n<0$, then it represents how many times the decimal place in d should be moved to the left. For example 3.24×10^3 represents 3240 (the decimal moved three places to the right) and 3.24×10^{-3} represents 0.00324 (the decimal moved three places to the left).

1.2.2 Uncertainty and Significant Figures

Measurements always have uncertainties. If you measure the thickness of the cover of this book using an ordinary ruler, your measurement is reliable only to the nearest millimeter, and your result will be 3 mm. It would be wrong to state this result as 3.00 mm; given the limitations of the measuring device, you can't tell whether the actual thickness is 3.00 mm, 2.85 mm, or 3.12 mm. But if you use a micrometer caliper, a device that measures distances reliably to the nearest 0.01 mm, the result will be 2.91 mm. The distinction between these two measurements is in

their uncertainty. The measurement using the micrometer caliper has a smaller uncertainty; it's a more accurate measurement. The uncertainty is also called the **error** because it indicates the maximum difference there is likely to be between the measured value and the true value. The uncertainty or error of a measured value depends on the measurement technique used.

In many cases the uncertainty of a number is not stated explicitly. Instead, the uncertainty is indicated by the number of meaningful digits, or **significant figures**, in the measured value. We gave the thickness of the cover of this book as 2.91 mm, which has three significant figures. By this we mean that the first two digits are known to be correct, while the third digit is uncertain. The last digit is in the hundredths place, so the uncertainty is about 0.01 mm. Two values with the same number of significant figures may have different uncertainties; a distance given as 137 km also has three significant figures, but the uncertainty is about 1 km.

Rules for Identifying Significant Figures

- Nonzero digits are always significant.
- Final or ending zeros written to the right of the decimal point are significant.
- Zeros written to the right of the decimal point for the purpose of spacing the decimal point are not significant.
- One or more zeros written to the immediate left of the decimal point are not significant.
- Zeros written between significant figures are significant.

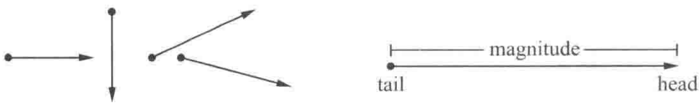
1.3 Scalars and Vectors

Some physical quantities, such as time, temperature, mass, and density, can be described completely by a single number with a unit. But many other important quantities in physics have a direction associated with them and cannot be described by a single number. A simple example is the motion of an airplane. To describe this motion completely, we must say not only how fast the plane is moving, but also in what direction. To fly from Shanghai to Beijing, a plane has to head north. The speed of the airplane combined with its direction of motion together constitutes a quantity called velocity. Another example is force. Giving a complete description of a force means describing both how hard the force pushes or pulls on the body and the direction of the push or pull.

> **Vectors and Scalars**
>
> A vector is a physical quantity with magnitude (size) and direction. A scalar is a physical quantity with magnitude (size) only.

Vectors are denoted by symbols with an arrow pointing to the right above it. For example, $\vec{a}$, $\vec{v}$ and $\vec{F}$ represent the vectors acceleration, velocity and force, meaning they have both a magnitude and a direction. Sometimes just the magnitude of a vector is needed. In this case, the arrow is omitted. In other words, F denotes the magnitude of vector $\vec{F}$.

Graphically, a vector can be drawn as a line with an arrowhead at its tip. The length of the line shows the vector's magnitude, and the direction of the line shows the vector's direction.



(a) Examples of vectors (b) Parts of a vector

Figure 1.1 Examples of vectors and Parts of a vector

1.4 Vector Addition and Subtraction

To understand more about vectors and how they combine, we start with the simplest vector quantity, displacement. Displacement is simply a change in position of a body. In Figure 1.2 we represent the change of position from point P_1 to point P_2 by a line from P_1 to P_2, with an arrowhead at P_2 to represent the direction of motion.

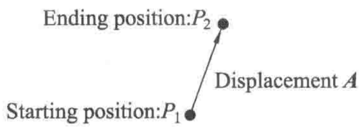


Figure 1.2 Displacement as a vector quantity

1.4.1 Vector Addition

When vectors are added, we need to add both a magnitude and a direction. For example, take 2 steps in the forward direction, stop and then take another 3 steps in the forward direction. The first 2 steps is a displacement vector and the second 3 steps is also a displacement vector. If we did not stop after the first 2 steps, we would have taken 5 steps in the forward direction in total. Therefore, if we add the displacement vectors for 2 steps and 3 steps, we should get a total of 5 steps in the forward direction(Figure 1.3 a).

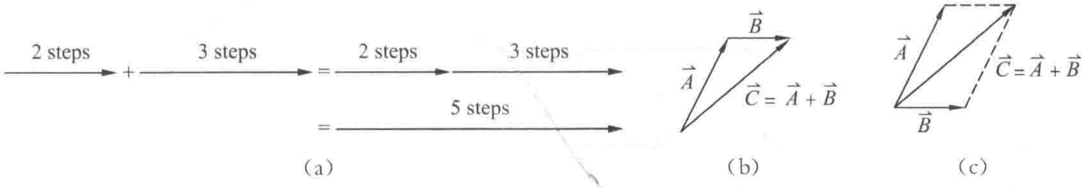


Figure 1.3 (a) Addition of two forward displacements. (b) Addition of two vectors with head-to-tail method. (c) addition of two vectors with parallelogram method.

Graphically, this can be seen by first following the first vector (two steps forward) and then following the second one (three steps forward). We add the second vector at the end of the first vector, since this is where we now are after the first vector has acted. The vector from the tail of the first vector (the starting point) to the head of the last (the end point) is then the sum of the vectors. This is the ***head-to-tail method*** of vector addition.

In general, When two vectors $\vec{A}$ and $\vec{B}$ are added, we usually place the tail of the second vector($\vec{B}$) at the head of the first vector ($\vec{A}$) as shown in Figure 1.3 b. The vector sum($\vec{C}$), or resultant, is the vector drawn from the tail of the first vector to the head of the last. We express this relationship symbolically as:

$$\vec{C} = \vec{A} + \vec{B}$$

Figure 1.3 c shows another way to represent the vector sum: If vector $\vec{A}$ and $\vec{B}$ are both drawn with their tails at the same point, vector $\vec{C}$ is the diagonal of a parallelogram constructed with $\vec{A}$ and $\vec{B}$ as two adjacent sides.

When we need to add more than two vectors, we may first find the vector sum of any two, add this vectorially to the third, and so on.

1.4.2 Vector Subtraction

If we take 5 steps forward and then subtract 3 steps forward we are left with only two steps forward.

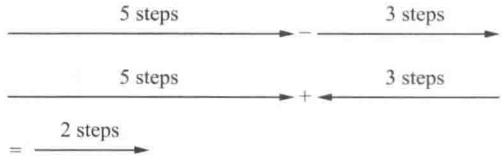


Figure 1.4 Subtracting a vector from the other is the same as adding a vector in opposite direction.

How could this happen? You originally took 5 steps forward but then you took 3 steps back. That backward displacement would be represented by an arrow pointing to the left (backwards) with length 3. The result of adding these two vectors is 2 steps forward.

Thus, subtracting a vector from another is the same as adding a vector in the opposite direction.

1.4.3 Techniques of Vector Addition

Two graphical techniques can be employed to find the resultant of two vectors: the head-to-tail method and the parallelogram method.

1.4.3.1 Head-to-Tail Method of Vector Addition

- Choose a scale and include a reference direction.
- Choose any of the vectors and draw it as an arrow in the correct direction and of the correct length-remember to put an arrowhead on the end to denote its direction.
- Take the next vector and draw it as an arrow starting from the arrowhead of the first vector in the correct direction and of the correct length.
- Continue until you have drawn each vector—each time starting from the head of the previous vector. In this way, the vectors to be added are drawn one after the other head-to-tail.
- The resultant is then the vector drawn from the tail of the first vector to the head of the last. Its magnitude can be determined from the length of its arrow using the scale. Its direction too can be determined from the scale diagram.

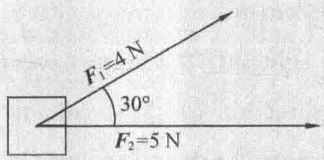
1.4.3.2 Parallelogram Method of Vector Addition

- Choose a scale and a reference direction.
- Choose either of the vectors to be added and draw it as an arrow of the correct length in the correct direction.
- Draw the second vector as an arrow of the correct length in the correct direction from the tail of the first vector.

- Complete the parallelogram formed by these two vectors.
- The resultant is then the diagonal of the parallelogram. The magnitude can be determined from the length of its arrow using the scale. The direction too can be determined from the scale diagram.

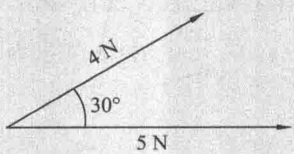
Example 1-1

A force of $F_1 = 5$ N is applied to a block in a horizontal direction. A second force $F_2 = 4$ N is applied to the object at an angle of 30° above the horizontal. Determine the net force acting on the block using the parallelogram method of accurate construction.

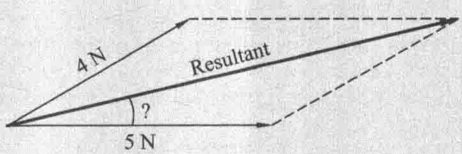


Answer

In this problem choose a scale of 1 cm = 1 N. We can now begin the accurate scale diagram. Let us draw F_1 first. According to the scale it has length 5 cm. Next we draw F_2. According to the scale it has length 4 cm. We make use of a protractor to draw this vector at 30° to the horizontal.



Next we complete the parallelogram and draw the diagonal. The resultant has a measured length of 8. 7 cm. We use a protractor to measure the angle between the horizontal and the resultant. We get 13. 3°.



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