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时代教育·国外高校优秀教材精选

21 世纪普通高等教育基础课规划教材

双语教学专用教材

西尔斯当代大学物理

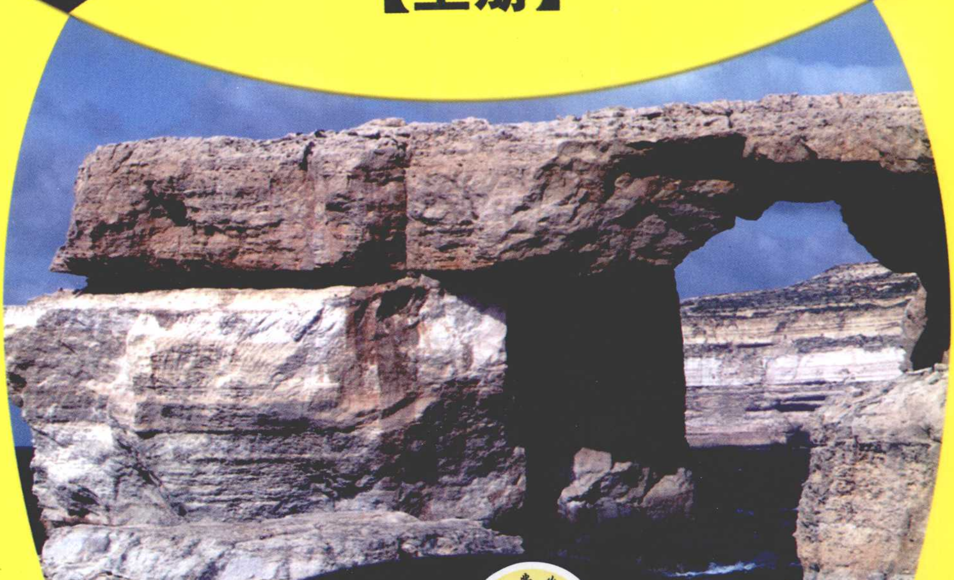
英文改编版（原书第11版）

Sears and Zemansky's
UNIVERSITY PHYSICS with Modern physics (11th Ed.)

（美）HUGH D. YOUNG & ROGER A. FREEDMAN 著

邓铁如 孟大敏 徐元英 等改编

【上册】



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机 械 工 业 出 版 社

本英文改编教材的原书——《西尔斯物理学》是几代编著者长达半个多世纪物理教育探索与创新的产物，其许多可圈可点的特色在美国乃至世界其他国家，影响了一代又一代的大学师生，是当今世界发行量最大的主流教材之一。

本教材分上下两册。本书是上册，主要内容有力学、热学、电磁学等。

本书既充分体现了原书的特色，又在适合我国国情方面有了新的特点，主要表现在：对原书取舍得当，篇幅适当，教材内容覆盖了教育部最新教学基本要求建议的75个A类知识点和部分B类知识点；教材95%以上是原书的文字，体现了原书教学理念的精华，整个教材体系具有更好的系统性和完整性；内容生动、丰富，图文并茂，举例鲜活，趣味性强，联系实际密切，强调概念理解，注重能力培养；每章的问题引入法、正文探索式的叙述法以及每节的思考题检测法等多种教学方法并用，将有效调动学生学习的积极性，提高学生学习的效能；所有例题都采用四步解题法：审题（Identify）、破题（Set up）、求解（Excute）和讨论（Evaluate），这种规范、科学的解题方式十分有利于学生形成思维清晰、表述准确、方法明确的解题习惯，并能逐步获得较强的解决实际问题的能力；英语行文规范、流畅，原汁原味，代表了当前科技英语文献的风格，是我国学生学习英文科技写作的极好范本。

本教材为高等学校理工科各专业学生的大学物理双语教学专用教材。由于与国内教材有很强的相关对应性，故对于希望了解物理知识英文表述的非双语教学的师生及其他科技工作者，本书也是一本十分有益的参考书。

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Preface

1. 关于原书、原作者

本书改编自培生教育出版公司（Pearson Education, Inc.）于 2004 年推出的西尔斯大学物理第 11 版（Sears and Zemansky's UNIVERSITY PHYSICS with modern physics, 11th edition，以下简称西书）。

西书是美国几代物理教育专家长达半个多世纪探索与改革的产物。初版由美国物理教育界领军人物 F. W. Sears 和 M. W. Zemansky 于 1949 年推出。西书作者提倡站在学生的角度探究式地展开讨论，强调讲透概念、原理与培养学生解题能力并重，在版面设计上作出有针对性的安排。这些探索成果对促进学生自主学习产生了较大反响。西书第 11 版的主要作者 H. D. Young 自 1973 年始成为 Sears 和 Zemansky 的合作者，参加第 5 版编写。前两位作者相继去世后，Young 从第 8 版起单独署名。他继承与完善了西书的导学式理念，使西书不仅在美国，而且在其他国家影响了一代又一代的大学师生，至今仍是发行量最大的主流教材之一。另两位作者 R. A. Freedman 与 A. L. Ford 分别自第 10 版、第 11 版参加编写工作。

西书曾于 20 世纪 50 年代以《西尔斯物理学》之名被翻译成中文在中国出版。当时该书受到我国大学物理教师的关注并作为教学参考书。至今我国物理教材中的一些讲法和习题都渊源于该书。机械工业出版社 2003 年影印出版了西书第 10 版。由于特色鲜明、角度新颖、讲解详尽、讨论深入，加之行文流畅，代表了当前英语科技文献流行风格，该影印版被一些高校选作物理双语课本，获得好评。

西书第 11 版的刚体力学、振动与波、热学、电磁学、波动光学、狭义相对论与量子物理基础等 6 部分（覆盖大学物理课程教学内容 9 成以上）涵盖的知识点、调用的数学知识以及达到的难度与深度，同国内流行教材吻合度很高，适合选作非物理类尤其是工科专业的大学物理双语教材。

西书第 11 版每章由一个开篇问题（Opening question）引导，每节由一道理解检测题（Test your understanding question）收尾、以便学生阅读时自测，引导学生深入思考、探究。其答案都列于每章之末，以供核对。在课文适当处以 Caution 为标志点出学生常犯的通病和易产生的误解，警醒读者规避。这些编排有助于提升学生读书的效果。

西书第 11 版另一特点是注重传授解题技巧。除配有大量例题之外，西书编者将解题的思路与步骤概括为审题（identify）、破题（set up）、求解（execute）与评价（evaluate）四个环节。首先审定该问题涉及的物理原理、概念，确定待求的目标变量；其次列出相应的方程或方程组，明确哪些是已知量、哪些是待求的未知量；再次完成数学运算，得出结果；最后根据物理背景要求，评价结果的合理性、有效性。其亮点在于，全书将各种物理问题分门别类，以 Problem-Solving Strategy 为标志列出某一类问题的审题思路、破题入口，求解的步骤及技巧，并在其后附以该类问题的若干示范例题，供学生揣摩、领会。课文中每则解题技巧与每道例题都按上述四个环节逐步讨论（改编版自第 6 章始），并借用首字母缩略词将这种解题方略称为

ISEE 方法。H. D. Young 认为持之以恒地按 ISEE 训练，有利于学生养成思维清晰、条理分明、表述规范的良好解题习惯，能使学生从面对习题不知所措过渡为训练有素，按部就班解题，从而减少失误，树立信心。ISEE 受到使用西书师生的欢迎，得到物理教学法研究人员的好评，值得我们借鉴。

那么，这样优秀的教材为什么还要改编呢？

2. 改编初衷

改革开放以来，尤其是在倡导双语教学的 21 世纪，国内引进出版的英文物理类教材可称汗牛充栋。虽然它们对我国教材建设、教学改革以及促进双语教学功不可没，但是，由于国情和教学理念的差异，探索双语教学的同仁们逐渐认识到：即使是优秀的国外一流教材，直接用作双语课本也未必是最适合的。笔者自 20 世纪 80 年代末，在合肥工业大学探索物理双语教学已历 20 载，深感直接选用外国优秀教材存在许多不尽人意之处。

首先是质点力学起点过低、展开太细、与中学重复甚多，所有英文原版物理教材概莫能外。以西书 11 版为例，洋洋洒洒 8 章 326 页，仍明显未达国内现行大学物理质点力学的深度与难度。教育部最新颁布的《理工科大学物理课程教学基本要求》（以下简称“基本要求”）指出，力学中除角动量、刚体外，“绝大多数概念学生在中学阶段已有接触，故教学中展开应适度，以避免重复感”。显然，目前的任何一本原版物理教材都与此精神不符。虽然“基本要求”对质点力学的建议学时仅 8～10 学时，不到课程总学时的 10%，但由于该部分排在大学物理教材之首，位居学生接受双语教学和接触原版教材之初，低水平的重复容易破坏学生的学习兴趣，成为教学中的拦路虎。笔者每轮教学至此都颇费周章，相信业内同仁亦有同感。20 世纪 80 年代中后期国内从事物理双语教学的许多学校就曾直接删去力学，从热学甚至电磁学开讲，笔者也曾试过，这当然是无奈之举。后来在探索中，笔者用几十页自撰讲义取代原书相应部分，化解了这一难题。

按“基本要求”精神，质点力学起点应定位于我国高中毕业生已达之水平。突出矢量运算与微积分思想方法的应用，提纲挈领地回顾运动学、动力学、功与能、动量与冲量、机械能与动量守恒定律等知识，并让学生通过解答涉及变加速度、变力等非用微积分不可的问题，深化认识。这一教案不难移植到双语教学中，难的是无法在原教材中挑出适用的章节甚至段落来呼应。作为替代，笔者将全英文的教案写得尽可能详细，以多媒体方式在讲课中展示，同时印发给学生作为讲义。这一教法能达到与国内教材持平的深度。自撰讲义虽列为 5 章，篇幅只几十页，但与建议学时相适应，体现了“展开应适度”的精神。讲义维持了体系的完整，实现了与后续内容的衔接，使大刀阔斧地删减前 8 章成为可能。由于采用这一教法，合肥工业大学物理双语教学近 5 年效果良好。这便是我们提出“有删有补”改编方案的缘起。

此外，原版教材篇幅浩大、扩展内容过多，也应在改编中一并解决。

3. 改编的具体构想

“基本要求”列出 75 个 A 类知识点，它们构成大学物理课程教学内容的基本框架，是核心内容。国内从事物理双语教学的同仁迫切希望有一本既保留引进教材长处和特色，又覆盖上述 A 类知识点、篇幅适当的英文物理教材。回应这一需求，国内曾出过自主撰写的英文教材，但难以传递原汁原味的行文风格；国内也出过缩编版，但因受原出版商“只删不补”的制约，为维持内容体系完整，删减力度不大，力学困惑依旧。

我们认为，最适用的双语教材应主体选自国外优秀一流教材，应以“基本要求”列出的A类知识点为改编删留的依据。对难以删留的质点力学，不妨以自撰讲义替代。

西书11版的刚体力学（第9，10两章，指原书序号，下同）、振动与波（第13，15两章）、热学（第17，18，19，20共4章）、电磁学（第21，22，23，24，25，27，28，29，30共9章）、波动光学（第32，33，35，36共4章）、近代物理（第37，38，39，40共4章）总计25章，它们与国内传统教材贴近，难度与数学要求相当，可全部保留，只需删去与中学重复的4小节（热膨胀、电容串并联、电功率、全反射）以及属于扩展内容的9小节（横波波速、物质相变、内燃机、直流电动机、电磁驻波、色散、光散射、全息、电磁波多普勒效应）。这25章是教学内容的主体，占改编版90%以上篇幅，保留这25章，便保证了原书特色、长处的承传及原汁原味文风的传递。

除删去质点力学8章之外，整章删除的还有不属于本课程内容的3章：静力学（第11章）、直流电路（第26章）、交流电（第31章）；属于扩展内容的8章：万有引力（第12章）、流体力学（第14章）、声音与听力（第16章）、几何光学与光学仪器（第34章）、原子结构（第41章）、凝聚态（第42章）、核物理（第43章）、粒子物理与宇宙学（第44章）。共计删除19章。

扩展内容比重大是国外教材的一大特色。适当讲授这些内容或供学生课外阅读固然可以深化理解，扩展眼界，起到开启新“知识窗口”、预留“知识接口”之功效，国内面向21世纪推出的教材不少都借鉴了这一特色，有的扩展内容近半。然而，在实际教学中，多数学生只浏览其中一部分，倒是教师研读得仔细。前述删去的扩展内容，作为中文教材，或者供教师参考用的原版教材都宜保留，而作为学生双语课本，则可另作别论，因为学生英文阅读量已十分浩大（平均每次2学时覆盖教材12页以上）。绝大多数学生无暇阅读扩展内容。再者，能在浏览中挑出感兴趣内容来阅读，对多数低年级学生来说力不从心。

保留的25章中仍有少数A类知识点未能覆盖或覆盖不足，这些欠缺可自删除的篇幅中挑出相关内容补齐。例如第16章第7节“拍”与第8节“多普勒效应”，分别改作第15章的第8、9两节；第41章第1节“氢原子”、第3节“电子自旋”和第4节“多电子原子与不相容原理”，分别改作第40章的第6、7、8节。第13章的第2节引入了相矢量，但未讲透，而补充的段落又在第31章交流电中被删去，需要将此段落挖出适当改动，然后补充到13章第2节中。

所有章节的删留都存在一个衔接整合问题，有大量案头工作要做。除此之外，我们还作了以下删减。

习题量大是国外教材又一特色。作为参考书固然多多益善，但作为课本，考虑到学生的浏览能力有限，我们按“基本要求”作了筛选，依建议学时的4~5倍选留习题，同时删去每章的小结、书末的照片出处及索引，并用中文的改编前言代替原书目录之前的附页。改编版将原书篇幅由1780页缩至800页，覆盖了“基本要求”列出的全部75个A类知识点，同时至少涉及14个B类知识点。

尽管自撰稿能化解质点力学的难题，但笔者深知自撰文字无法与原书风格衔接，只能退而求其次，按详细教案自撰讲义。用自撰讲义替代原书前8章实属不得已之举，为使自撰稿尽可能规范，笔者尽量从删去的8章中选出适用的段落与句子，尽量套用原书及其他优秀原版教材中的英语表述方式，使纯粹自撰的句子压缩到20页之内，只占改编版的3%，而原汁原味的英

文表述占到97%以上。何况这20页自撰稿中，公式图表还占了相当比重，使文字不地道的负面影响尽可能减小。

4. 鸣谢

有删有补的改编构想得到了机械工业出版社的大力支持。经多方争取，获得了国外原出版商的改编授权，使我们的构想得以施行。在改编方案拟订之初，机械工业出版社李永联编辑帮助笔者广泛征求了国内物理双语教学同行的意见，许多专家、学者热情鼓励，不吝赐教，笔者深受感动。昆明理工大学王安安教授、北京交通大学滕小瑛副教授、成都电子科技大学王慧教授、湖南大学张智教授、浙江大学吴泽华教授、重庆邮电大学梁斌教授等，都根据自己双语教学的经验和体会给出了很好的建议。西安交通大学吴百诗教授在百忙中审阅了本书的改编方案与说明，并提出了中肯的意见。美国马里兰大学巴尔的摩分校的 Lily 博士悉心审订了自撰讲义稿。

笔者在探索双语教学的20年中，始终得到合肥工业大学分管教学的校领导、教务处、理学院及大学物理教研室领导的鼓励与支持，他们对本书的改编也极为关注。

中国科学技术大学井思聪教授担任本书主审，对全书的框架结构、删留取舍的合理性等进行了审查，并从更适应教学规律的角度提出了有益的建议和意见。

全体改编者愿在此对上述专家、学者及领导表示衷心的感谢!

5. 结语

我们希望提供一本反映美国最新主流教材特色，保持活泼生动、流畅规范、原汁原味语言风格的英文物理教材；希望该教材能覆盖教育部最新“教学基本要求”提出的全部核心内容，达到国内主流教材已达到的深度，同时满足篇幅适当、成本价格与国内教材相当的要求，供开展物理双语教学师生选用。

本书改编分工如下：邓铁如教授（现退休后兼职于宁波大红鹰学院）担任主编，负责改编方案的制定、前5章的撰稿以及全书的统稿；副主编孟大敏老师负责第6～13章的改编与多媒体课件设计；副主编徐元英老师负责第14～20章的改编及自撰讲义配图；宋逢泉老师负责第21～25章的改编及配套网络制作；景佳老师负责第26～30章的改编及多媒体课件制作。

限于水平，自撰稿失误在所难免，改编中取舍也有不周之处，欢迎业内同仁们及广大师生批评指正。

全体改编者

2009年

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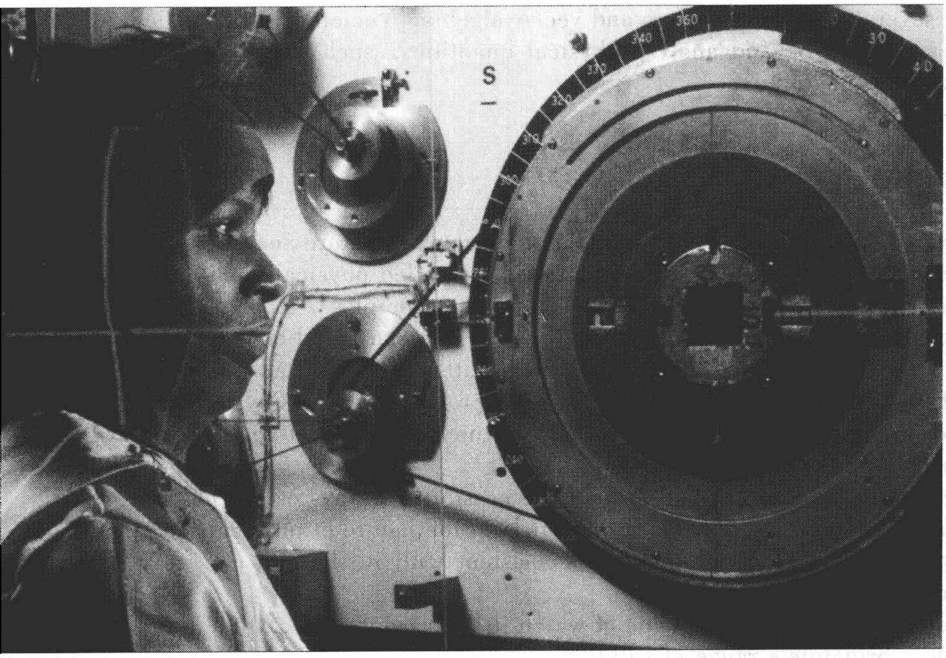
PHYSICAL QUANTITIES AND VECTORS 1



Accurate measurement is essential in medical applications of physics. The laser beams shining on this cancer patient form across-hairs on the site of a tumor, which is then bombarded by a stream of high-energy neutrons coming from the square aperture on the right. The neutrons deposit their energy in the tumor, stopping its growth and, ideally, destroying it completely. Because the narrow neutron beam is very accurately targeted, little damage occurs to the healthy tissue surrounding the tumor.

? Subatomic particles used in cancer therapy can be aimed at a tumor with an accuracy of 100 micrometers. How many human blood cells laid side by side would span this distance?

Why study physics? For two reasons. First, physics is one of the most fundamental of the sciences. Scientists of all disciplines make use of the ideas of physics, from chemists who study the structure of molecules to paleontologists who try to reconstruct how dinosaurs walked. The principles of physics play an essential role in the scientific quest to understand how human activities affect the atmosphere and oceans, and in the search for alternative sources of energy. Physics is also the foundation of all engineering and technology. No engineer could design any kind of practical device without first understanding the basic principles involved. No engineer could design a DVD player, a flat-screen TV, an interplanetary spacecraft, or even a better mousetrap without first understanding the basic laws of physics.

But there's another reason. The study of physics is 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. Our present understanding of the physical world has been built on the foundations laid by scientific giants such as Galileo, Newton, Maxwell, and Einstein, and their influence has extended far beyond science to affect profoundly the ways in which we live and think . You can share some of the excitement of their discoveries when you learn to use physics to solve practical problems and to gain insight into everyday phenomena. 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.

In this opening chapter, we'll go over some important preliminaries that we'll need throughout our study. We'll discuss the nature of physical theory and the use of idealized models to represent physical systems. We'll introduce the systems of units used to describe physical quantities and discuss ways to describe the accuracy of a number. We'll look at examples of problems for which we can't (or don't want to) find a precise answer, but for which rough estimates can be useful and interesting . Finally, we'll study several aspects of vectors and vector algebra. Vectors will be needed throughout our study of physics to describe and analyze physical quantities, such as velocity and force, that have direction as well as magnitude.

1.1 | The Nature of Physics

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

The development of physical theories is always a two-way process that starts and ends with observations or experiments. This development often takes an indirect path, with blind alleys, wrong guesses, and the discarding of unsuccessful theories in favor of more promising ones. Physics is not simply a collection of facts and principles; it is also the process by which we arrive at general principles that describe how the physical universe behaves.

No theory is ever regarded as the final or ultimate truth. The possibility always exists that new observations will require that a theory be revised or discarded. It is in the nature of physical theory that we can disprove a theory by finding behavior that is inconsistent with it, but we can never prove that a theory is always correct.

Every physical theory has a range of validity outside of which it is not applicable. Often a new development in physics extends a principle's range of validity.

1.2 | Idealized Models

In physics a model is a simplified version of a physical system that would be too complicated to analyze in full detail.

For example, suppose we want to analyze the motion of a baseball thrown through the air. How complicated is this problem? The ball is neither perfectly spherical nor perfectly rigid; it has raised seams, and it spins as it moves through the air. Wind and air resistance influence its motion, the earth rotates beneath it, the ball's weight varies a little as its distance from the center of the earth changes, and so on. If we try to include all these things, the analysis gets hopelessly complicated. Instead, we invent a simplified version of the problem. We neglect the size and shape of the ball by representing it as a point object, or particle. We neglect air resistance by making the ball move in a vacuum, we ignore the earth's rotation, and we make the weight constant. Now we have a problem that is simple enough to deal with.

To make an idealized model of the system, we have to overlook quite a few minor effects to concentrate on the most important features of the system. Of course, we have to be careful not to neglect too much. When we use a model to predict how a system will behave, the validity of our predictions is limited by the validity of the model. When we apply physical principles to complex systems, we always use idealized models, and we have to be aware of the assumptions we are making. In fact, the principles of physics themselves are stated in terms of idealized models; we speak about point masses, rigid bodies, ideal gases, and so on. Idealized models play a crucial role throughout this book.

1.3 | Standards and Units

As we learned in Section 1.1, physics is an experimental science. Experiments require measurements, and we generally use numbers to describe the results of measurements. Any number that is used to describe a physical phenomenon quantitatively is called a **physical quantity.** For example, two physical quantities that describe you are your weight and your height. Some physical quantities are so fundamental that we can define them only by describing how to measure them. Such a definition is called an **operational definition.** Some examples are measuring a distance by using a ruler, and measuring a time interval by using a stopwatch. In other cases we define a physical quantity by describing how to calculate it from other quantities that we can measure. Thus we might define the average speed of a moving object as the distance traveled (measured with a ruler) divided by the time of travel (measured with a stopwatch).

When we measure a quantity, we always compare it with some reference standard. Such a standard defines a **unit** of the quantity. The meter is a unit of distance, and the second is a unit of time. When we use a number to describe a physical quantity, we must always specify the unit that we are using; to describe a distance simply as "4.56"wouldn't mean anything.

To make accurate, reliable measurements, we need units of measurement that do not change and that can be duplicated by observers in various locations. The system of units used by scientists and engineers around the world is commonly called "the metric system, "but since 1960 it has been known officially as the **International System,** or SI (the abbreviation for its French name, *System International*). A list of all SI units is given in Appendix A, as are definitions of the most fundamental units.

The definitions of the basic units of the metric system have evolved over the years. When the metric system was established in 1791 by the French Academy of Sciences, the meter was defined as one ten-millionth of the distance from the North Pole to the equator (Fig.1.1). The second was defined as the time required for a pendulum one meter long to swing from one side to the other. These definitions were cumbersome and hard to duplicate precisely, and by international agreement they have been replaced with more refined definitions.

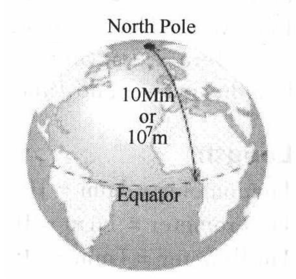


Fig.1.1 In 1791 the distance from the North Pole to the equator was defined to be exactly 10^7 m. With the modem definition of meter this distance is about 0.02% more than 10^7 m.

Time

From 1889 until 1967, the unit of time was defined as a certain fraction of the mean solar day, the average time between successive arrivals of the sun at its highest point in the sky. The present standard, adopted in 1967, is much more precise. It is based on an atomic clock, which uses the energy difference between the two lowest energy states of the cesium atom. When bombarded by microwaves of precisely the proper frequency, cesium atoms undergo a transition from one of these states to the other. One **second** is defined as the time required for 9, 192, 631, 770 cycles of this microwave radiation.

Length

In 1960 an atomic standard for the meter was also established, using the wavelength of the orange-red light emitted by atoms of krypton(^{86}Kr) in a glow discharge tube. Using this length standard, the speed of light in a vacuum was measured to be 299, 792, 458m/s. In November 1983, the length standard was changed again so that the speed of light in a vacuum was *defined* to be precisely

299, 792, 458m/s. The meter is defined to be consistent with this number and with the above definition of the second. Hence the new definition of the **meter** is the distance that light travels in a vacuum in 1/299, 792, 458 second. This provides a much more precise standard of length than the one based on a wavelength of light.

Mass

The standard of mass, the **kilogram,** is defined to be the mass of a particular cylinder of platinum-iridium alloy. That cylinder is kept at the International Bureau of Weights and Measures at Sevres, near Paris. An atomic standard of mass would be more fundamental, but at present we cannot measure masses on an atomic scale with as much accuracy as on a macroscopic scale. The *gram* (which is not a fundamental unit) is 0.001 kilogram.

Unit Prefixes

Once we have defined the fundamental units, it is easy to introduce larger and smaller units for the same physical quantities. In the metric system these other units are related to the fundamental units (or, in the case of mass, to the gram) by multiples of 10 or $\frac{1}{10}$. Thus one kilometer (1km) is 1000meters, and one centimeter (1cm) is $\frac{1}{100}$meter. We usually express multiples of 10 or $\frac{1}{10}$ in exponentia. notation: $1000 = 10^3$, $\frac{1}{1000} = 10^{-3}$, and so on. With this notation, $1\text{km} = 10^3\text{m}$ and $1\text{cm} = 10^{-2}\text{m}$.

The names of the additional units are derived by adding a **prefix** to the name of the fundamental unit. For example, the prefix "kilo-, "abbreviated k, always means a unit larger by a factor of 1000; thus

1 kilometer = 1 km = 10^3 meters = 10^3 m

1 kilogram = 1 kg = 10^3 grams = 10^3 g

1 kilowatt = 1 kW = 10^3 watts = 10^3 W

Here are several examples of the use of multiples of 10 and their prefixes with the units of length, mass, and time.

Length

1 nanometer = 1 nm = 10^{-9} m (a few times the size of the largest atom)

1 micrometer = 1 μm = 10^{-6} m (size of some bacteria and living cells)

1 millimeter = 1 mm = 10^{-3} m (diameter of the point of a ballpoint pen)

1 centimeter = 1 cm = 10^{-2} m (diameter of your little finger)

1 kilometer = 1 km = 10^3 m (a 10-minute walk)

Mass

1 microgram = 1 μg = 10^{-6} g = 10^{-9} kg(mass of a very small dust particle)

1 milligram = 1 mg = 10^{-3} g = 10^{-6} kg (mass of a grain of salt)

1 gram = 1 g = 10^{-3} kg (mass of a paper clip)

Time

1 nanosecond = 1 ns = 10^{-9} s (time for light to travel 0.3m)

1 microsecond = 1 μs = 10^{-6} s(time for an orbiting space shuttle to travel 8mm)

1 millisecond = 1 ms = 10^{-3} s (time for sound to travel 0.35m)

Unit Consistency

We use equations to express relationships among physical quantities, represented by algebraic symbols. Each algebraic symbol always denotes both a number and a unit. For example, d might represent a distance of 10m, t a time of 5s, and v a speed of 2m/s.

An equation must always be **dimensionally consistent.** You can't add apples and automobiles; two terms may be added or equated only if they have the same units. For example, if a body moving with constant speed v travels a distance d in a time t, these quantities are related by the equation

$$d = vt \tag{1.1}$$

If d is measured in meters, then the product vt must also be expressed in meters. Using the above numbers as an example, we may write

$$10\text{m} = \left(2\frac{\text{m}}{\not{\text{s}}}\right)(5\not{\text{s}})$$

Because the unit 1/s on the right side of the equation cancels the unit s. the product vt has units of meters, as it must. In calculations, units are treated just like algebraic symbols with respect to multiplication and division.

CAUTION When a problem requires calculations using numbers with units, *always* write the numbers with the correct units and carry the units through the calculation as in the example above. 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.

1.4 | 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 3mm. It would be *wrong* to state this result as 3.00mm; given the limitations of the measuring device, you can't tell whether the actual thickness is 3.00mm, 2.85mm, or 3.11mm. But if you use a micrometer caliper, a device that measures distances reliably to the nearest 0.01mm, the result will be 2.91mm. 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.

We often indicate the **accuracy** of a measured value—that is, how close it is likely to be to the true value—by writing the number, the symbol ±, and a second number indicating the uncertainty of the measurement. If the diameter of a steel rod is given as(56.47 ±0.02) mm, this means that the true value is unlikely to be less than 56.45mm or greater than 56.49mm. In a commonly used shorthand notation, the number 1.6454(21) means 1.6454 ±0.0021. The numbers in parentheses show the uncertainty in the final digits of the main number.

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 2.91mm, 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 hundredth place, so the uncertainty is about 0.01mm. Two values with the *same* number of significant figures may have *different* uncertainties; a distance given as 137km also has three significant figures, but the uncertainty is about 1km.

When we calculate with very large or very small numbers, we can show significant figures much more easily by using **scientific notation,** sometimes called **powers-of-10 notation.** The distance from the earth to the moon is about 384, 000, 000m, but writing the number in this form gives no indication of the number of significant figures. Instead, we move the decimal point eight places to the left (corresponding to dividing by 10^8) and multiply by 10^8. That is,

$$384,000,000\text{m} = 3.84 \times 10^8\text{m}$$

In this form, it is clear that we have three significant figures. The number 4.00×10^{-7} also has three significant figures, even though two of them are zeros. Note that in scientific notation the usual practice is to express the quantity as a number between 1 and 10 multiplied by the appropriate power of 10. Table1.1 summarizes the rules for significant figures.

Table1.1 Using Significant Figures

Mathematical operation	Significant figures in result
Multiplication or division	No more than in the number with the fewest significant figures *Example*: $(0.745 \times 2.2)/3.885 = 0.42$ *Example*: $(1.32578 \times 10^7) \times (4.11 \times 10^{-3}) = 5.45 \times 10^4$
Addition or subtraction	Determined by the number with the smallest uncertainty(i.e., the fewest digits to the right of the decimal point) *Example:* $27.153 + 138.2 - 11.74 = 153.6$

Note: In this book we will usually give numerical values with three significant figures.

When an integer or a fraction occurs in a general equation, we treat that number as having no uncertainty at all. For example, in the equation $v^2 - v_0^2 = 2a(x - x_0)$, which is Eq.(2.9) in Chapter 2, the coefficient 2 is *exactly* 2. We can consider this coefficient as having an infinite number of significant figures (2.000000...). The same is true of the exponent 2 in v^2 and v_0^2.

1.5 | Vectors and Scalars

Some physical quantities, such as time, temperature, mass, density, and electric charge, can be described completely by a single number with a unit. But many other important quantities have a direction associated with them, such as velocity and force, and cannot be described by a single number.

When a physical quantity is described by a single number, we call it a **scalar quantity.** In contrast, a **vector quantity** has both a magnitude and a direction in space. Calculations with scalar quantities use the operations of ordinary arithmetic. However, combining vectors requires a different set of operations. We usually represent a vector quantity by a single letter, such as $\vec{A}$. In this book we always print vector symbols in ***boldface italic type with an arrow above them.*** The arrow is a reminder that vectors have direction. If you don't distinguish between scalar and vector quantities in your notation, you probably won't make the distinction in your thinking either, and hopeless confusion will result.

When drawing any vector, we always draw 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.

We usually represent the magnitude of a vector quantity by the same letter used for the vector, but in *light italic type* with no arrow on top. An alternative notation is the vector symbol with vertical bars on both sides: (magnitude of $\vec{A}$) $= A = |\vec{A}|$. We also note that a vector can never be equal to a scalar because they are different kinds of quantities. Each term in a equation must belong to