爱上科学
Science

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爱上科学

INTRODUCING • 物理系列
PHYSICS

电的奥秘

ELECTRICITY AND ELECTRONICS 双语版

[英] Graham Bateman 编
糜修尘 译
熊雪亭 审

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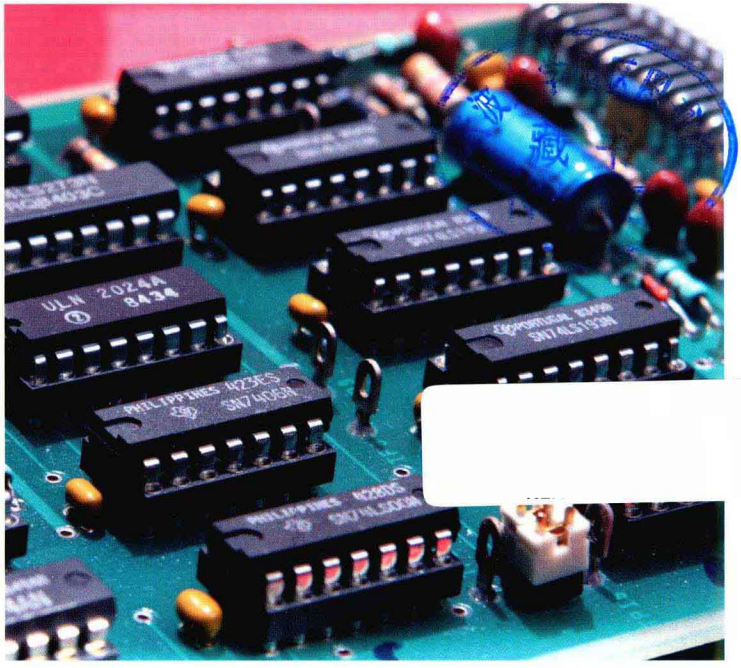

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内容提要

《爱上科学》系列科普丛书为读者全面地讲述了科学知识和原理，以通俗的文字、生动的图表为特色，每本书介绍一个或几个主题。从日常生活中有趣的现象出发，引导和培养读者学习的兴趣，扩宽读者的视野，同时还可以帮助读者学习英语词汇、练习英语阅读。丛书涵盖物理、化学、生物、科技与发明这4个系列。适合对科学知识感兴趣的广大科普爱好者阅读。

本书是物理系列中的一本。物理系列解释和说明了物理学知识及其发展史，包含物理学发展史许多重大的物理发现以及著名的物理学家。用通俗生动的语言展示物理学的魅力，引发读者对物理学的兴趣和探索。同时包含丰富有趣的物理小实验。

本书涵盖从基础电学到高中电学的很多电学知识，用青少年感兴趣的方式展示物理电学的魅力。书中含有“科学词汇”栏目，提取每章重点知识词汇。同时还有“试一试”栏目，包含丰富有趣的家庭小实验，有助于提高大家的动手能力。

丛书编委会

丛书序

这是一个科技新时代，我们曾经认为遥不可及的科学，时刻围绕在我们身边。你是否曾经怀疑过所谓的“2012，世界末日”，或者好奇过在地下高速飞驰的地铁，抑或每天都在关注着PM2.5……这说明科学已然走进了你的生活。学习科学，分享科学，爱上科学，让我们共同聆听来自科学的声音。

《爱上科学》系列科普丛书是一套引进版系列科普丛书，译自英国大型出版商棕熊图书（BROWN BEAR BOOKS）有限公司出版的著名系列科普图书《Facts At Your Fingertips》，其独特的科学解读视角、生动的科普画面、优美的图文设计，得到了欧洲读者的青睐，尤其是得到了欧洲青少年的极大欢迎。本丛书为读者全面地讲述了各个领域的基础科学知识和基本事实，以精彩的主题、通俗的文字、生动的画面为特色，从我们身边的素材和现象出发，激发和培养读者学习的兴趣。

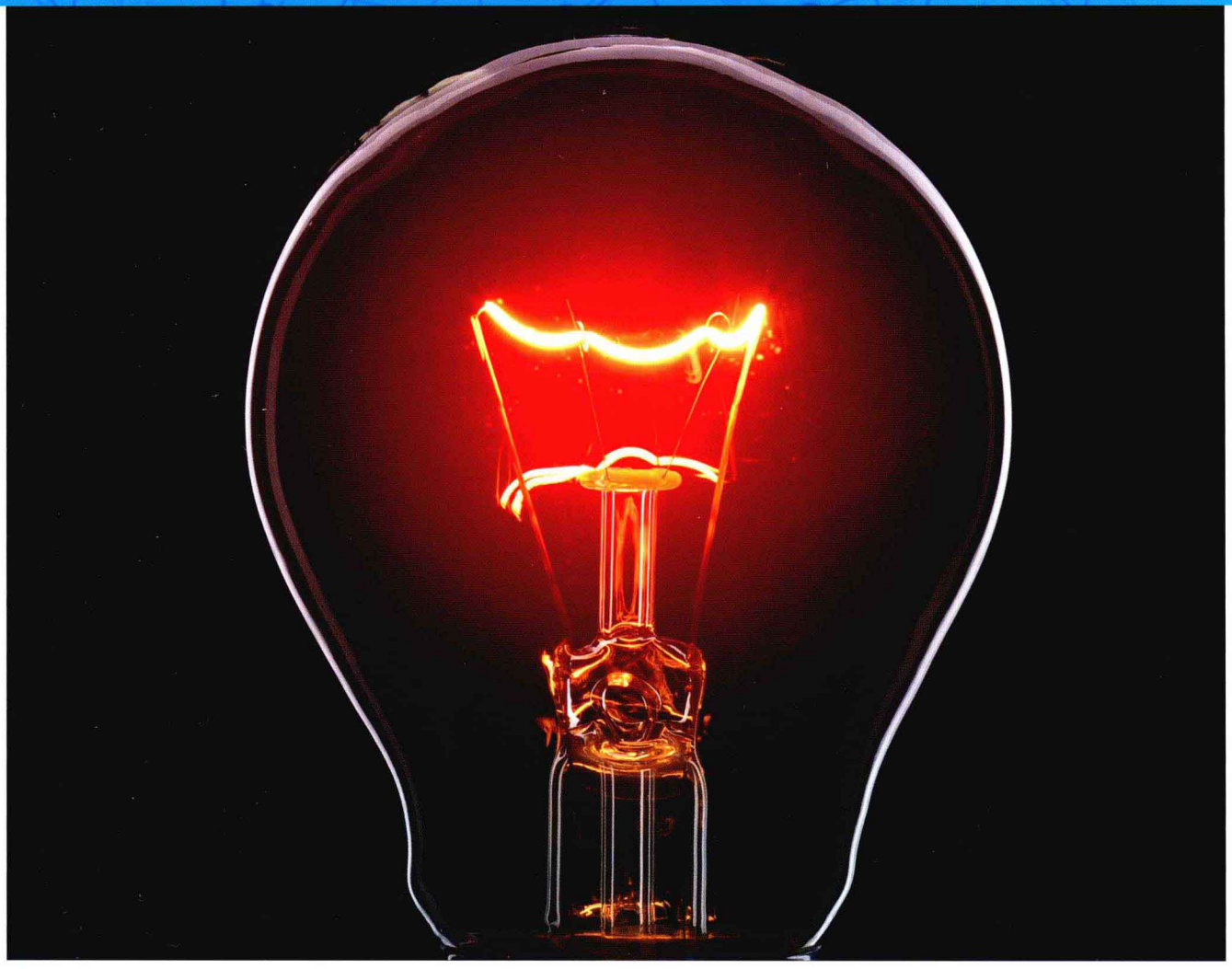
丛书涵盖物理、化学、生物、科技与发明四大系列。物理系列阐释和说明了物理学知识及其发展史，包含对物理学发展史许多重大的物理发现以及著名的物理学家的介绍。化学系列主要阐释现代化学的基本概念，涵盖化学反应、有机化学、生物化学、金属、非金属、分子、原子、物态等多方面内容。生物系列主要阐释生命科学的基本概念，并探讨有关生物学的各个方面，包括植物学、微生物学、动物和人类、遗传学、细胞生物学以及生命形式等。科技与发明系列主要介绍各种科技成果以及相关发明，覆盖多个领域，包括建筑、交通、医学、军事、能源以及航空航天等，指导读者认知和学习各种科学技术，拓宽视野，引发思考，提升创新能力以及发明意识。

本丛书还具有中英双语的独特设计，让读者在阅读中文时，能对照性地阅读英语原文，为他们提高科学领域的英文阅读能力以及扩展科学类英语词汇量提供了很好的帮助。

丛书中还有“试一试”栏目，该栏目包含了丰富有趣的家庭小实验，为大家在生活实践中验证科学知识提供了更多的选择。

学无止境，让我们一起爱上科学！

目录 CONTENT



《爱上科学——电的奥秘》讲述了物理学发展中与电相关的重要成果和重要实验。物理学中的电围绕着电子展开。电子是原子中带负电的微小粒子。介绍过电子的发现后，本书继续介绍了当原子中的电子发生变化时产生的电荷和电荷的性质。穿过导体的电子束能够产生电流。自然界中，一些材料很容易导电，还有一些则根本不导电。各种材料的导电性和电流产生的方式在本书中都有介绍。交流电和直流电的产生方式也在本书中作了介绍。最后，本书还介绍了电子学的发展历程，从早期的电子三极管到半导体材料的发现再到现在的微芯片和其他的晶体管设备。

本书中含有丰富的示意图和照片，同时还包含了电学中的重要内容和为物理学发展做出过重大贡献的著名科学家。本书含有2个特色版块，“科学词汇”能够帮助你理解本书的内容；“试一试”帮助你进行那些能够踏出实践的第一步的实验。

THE EMPTY ATOM

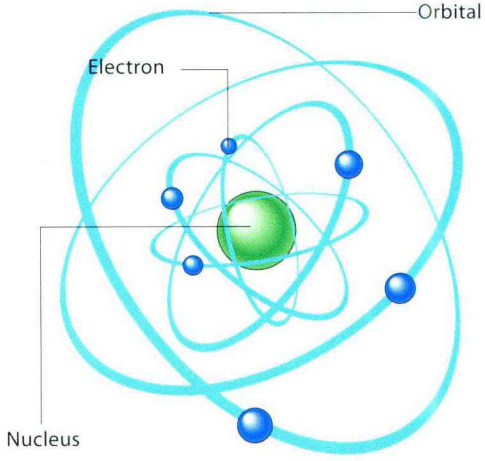
The whole of modern electronics is built on the properties of one tiny particle that is found in the atoms of all elements—the electron.

At the end of the 19th century most physicists were convinced that chemical elements existed in the form of atoms–tiny units of matter that are normally undivided and indivisible. But nothing at all was known about their internal structure.

The first glimpse into the atom came when the English physicist William Crookes (1832–1919) invented the Crookes tube. It was a glass bottle in which the air pressure could be reduced to a ten-thousandth of its normal value. Two electrodes protruded into the lowpressure gas. When a high voltage was applied across the electrodes, glowing colored patches and bands of light appeared in the tube. The light changed in complex ways as the pressure and voltage were altered.

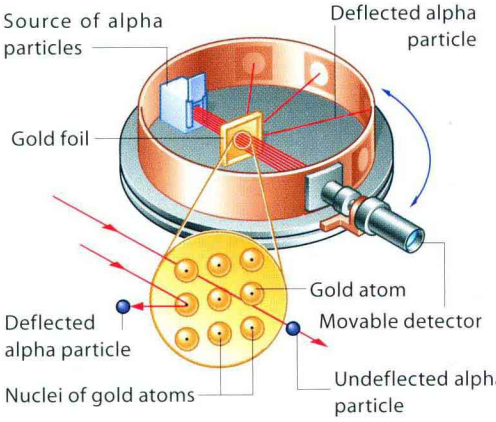
ELECTRONS IN ORBITALS

In an atom the negatively charged electrons surround the positively charged nucleus. The regions in which they are found are known as orbitals. Shown here is an atom of carbon, with its six electrons.



THE HEART OF THE ATOM

Ernest Rutherford (1871-1937) allowed positively charged alpha particles to bombard a thin foil of gold. Most passed straight through, but a small number were deflected through large angles, showing they had bounced off a positively charged core, or nucleus, within the atom.



Mysterious rays

Crookes was able to show that the bands were caused by something moving from the negative electrode (the cathode) toward the positive electrode (the anode). He gave the name

SCIENCE WORDS

- **Anode:** A positive electrical terminal on a device such as a battery. Electrons flow into the device through the anode. See also Cathode.
- **Atom:** The smallest part of a chemical element that can exist on its own. It has a central nucleus, surrounded by electrons.
- **Cathode:** A negative electrical terminal on a device such as a battery. Electrons flow into or out of the device through the cathode. See also Anode.

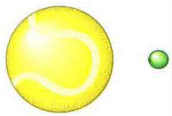
"cathode rays" to these streams of mysterious objects. Another English physicist, J. J. Thomson (1856–1940), applied electric and magnetic fields to cathode rays. He found that the rays consisted of identical, negatively charged particles. They were the same no matter what sort of gas was in the tube, and they seemed to be much lighter than even the lightest atom. Thomson claimed that these particles were all fragments of atoms. They were soon named "electrons" from the Greek word *elektron*, which means "amber" (static electricity was first made by rubbing amber).

Cathode rays consist of electrons that have emerged at the cathode, and flow from the cathode toward the anode. They collide with gas atoms on the way, knocking further electrons out of those atoms.

If the normally electrically neutral atom contains negatively charged electrons, it had to contain equal amounts of balancing positive charge. So how were the electrons and the positive charge arranged in the atom?

Deeper into the atom

A New Zealand-born physicist, Ernest Rutherford (1871–1937), probed deeper into the atom in 1911. For this he used alpha particles, which are given out in radioactivity. They are helium atoms that have lost their electrons and are thus positively charged. Rutherford allowed them to strike a thin sheet of gold. Most went right through, but a tiny number were deflected, some of them quite strongly.



The only way he could explain this was to suppose that the positive charge was concentrated in a tiny core, or nucleus, at the center of the atom. Most alpha particles missed the nuclei, but some came very close, were repelled, and bounced back.

The nucleus proved to have one ten-thousandth the diameter of the atom. Electrons roam through the outer parts of the atom—relatively speaking, a truly enormous volume.

TRY THIS

The scale of the atom

Electronics involves electrons, and electrons come from atoms. An atom consists of a central nucleus surrounded by one or more orbiting electrons. But how solid is an atom? And how small is an electron? In this project you will make a scale model of a simple atom.

What to do

The simplest atom is the hydrogen atom. It has a nucleus consisting of a single proton, and a single electron orbits this nucleus. In this model, a tennis ball represents the nucleus, and a pea represents the electron. Their sizes are in about the right proportion, so you can see how much smaller the electron actually is. But how big is the hydrogen atom?

To make a scale model of the atom, you will have to go outdoors to a tennis court (or an area of similar size). Place the tennis ball at one corner of the court. Then walk over and place the pea at the corner diagonally opposite the ball. If you don t have access to a tennis court, place the pea about 27 yards (25 meters) from the tennis ball. This distance is in about the right proportion to the "proton" and the "electron," so you can see that a hydrogen atom is mostly empty space. So are all other kinds of atom. If you keep hold of the tennis ball, try to persuade a friend to hold the pea and run around you in a big circle about 55 yards (nearly 50 meters) across. This is modeling what the electron does in a hydrogen atom, though it doesn t get out of breath like your friend will!

This model of the hydrogen atom is very roughly to scale, with the tennis ball standing for the nucleus and a pea representing the electron. Even at this scale the pea is slightly too large, but the model emphasizes that an atom consists mostly of empty space.

空空的原子

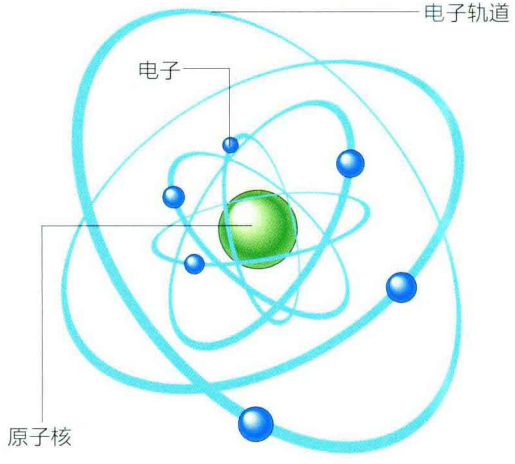
整个现代电子学都是建立在一个小小粒子的性质的基础上。它在所有的原子当中都存在，这个微粒就是电子。

19世纪末期，大部分物理学家都认为化学元素以原子的形式存在，而且原子被认为是物质的最小组成单位。那时原子被认为是不可分割的，因此它的内部结构并不为人所知。

对原子结构的探索首先由英国物理学家威廉·克鲁克斯（1832—1919）进行。他发明了克鲁克斯管（阴极射线管）。这是一个内部气压仅仅为万分之一个大气压的接近真空的玻璃管，玻璃管内装有两个电极。当我们给电极上施加高电压时，能够在管内观察到光斑和光带。当电压发生变化时，管内的光也会发生复杂的变化。

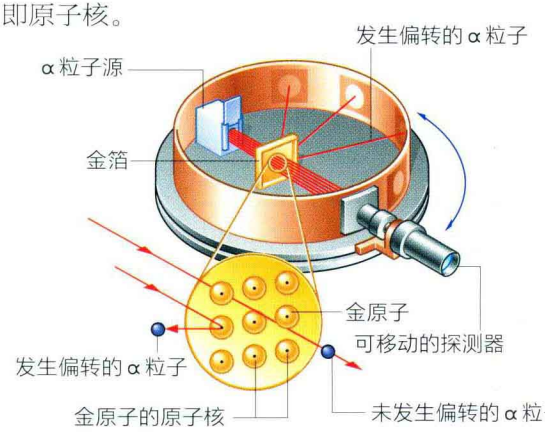
环绕中的电子

原子由带正电的原子核和环绕它的带负电的电子组成。电子所在的区域被称为电子轨道。图1.1中展示了有6个电子环绕的碳原子。



原子的中心

欧尼斯特·卢瑟福（1871—1937）用带正电的α粒子去撞击一片金箔。大部分α粒子直接穿过了金箔，但仍有小部分α粒子产生了大角度的偏转。这表明它们撞上了原子带正电的核心，即原子核。



奇妙的射线

克鲁克斯证明了光带是由从负电极（阴极）向正电极（阳极）移动的物质产生的，他把这一束神秘的物质命名为“阴极射线”。另一位英国物理学

科学词汇

- **阳极：**电池等设备中的正极，电子从阳极进入设备当中。参阅阴极。
- **阴极：**电池等设备中的负极，电子从阴极流出设备。参阅阳极。
- **原子：**化学元素的最小组成单元。由核心的原子核和围绕原子核的电子组成。

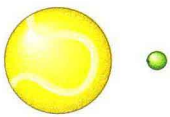
家约瑟夫·约翰·汤姆逊（1856—1940）通过给阴极射线施加电场和磁场的影响，发现阴极射线是由独立的带负电的微粒组成的。无论管中充满着何种气体，实验结果并没有因此而受影响。而且它们似乎比最轻的原子还要轻。汤姆逊认为这些微粒都是原子的碎片。接着，它们被命名为“电子”（electrons），这个单词来自于希腊语中的*elektron*，意思是琥珀（最早静电是由布摩擦琥珀产生的）。

阴极射线由阴极产生的电子组成，并且从阴极向阳极流动。在行进过程中，它们与气体原子发生碰撞，从气体原子中撞击出更多的电子。

如果不带电的原子中包含着带负电的电子，那么原子也必须带着等量的正电。电子和正电荷在原子中是怎么排列的呢？

深入原子

新西兰裔的物理学家欧尼斯特·卢瑟福（1871—1937）在1911年更加深入地探究了原子的内部结构。为了实现这一目标，他使用了由放射性材料产生的α粒子。它们是失去了电子的氦原子，因此它们带正电。卢瑟福使它们撞击一片金箔，大部分α粒子直接穿过了金箔，但有小部分发生了偏转，并且其中有些偏转的角度十分大。



唯一的解释是，假设正电荷集中在原子的核心中，即原子核。大部分α粒子没有撞击到原子核，不过一些α粒子十分靠近原子核，因此被排斥和反弹。

后来人们知道，原子核的直径是原子的万分之一。电子在原子内占据的是一个相对而言十分巨大的空间。

试一试

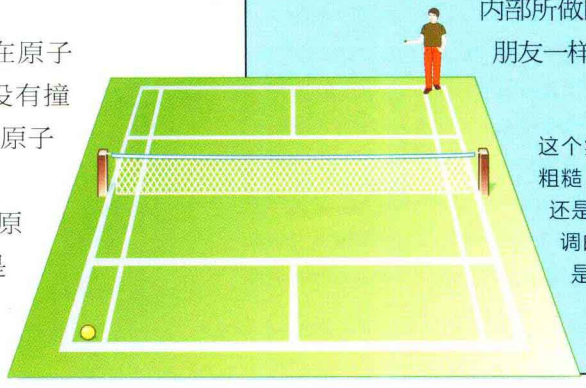
原子的规模

电子学和电子有关，而电子处于原子之中。原子由中心的原子核和围绕着原子核的一个或多个电子组成。但是原子究竟是什么结构？电子究竟有多小？在这个计划中你会建造一个原子的比例模型。

步骤

最简单的原子是氢原子。它由只有一个质子的原子核和一个环绕着原子核的电子组成。在我们建造的模型中，网球代表着原子核，豌豆则代表着电子。它们的大小刚好符合比例。现在你知道电子究竟有多小了，但氢原子究竟有多大呢？

为了建造原子的比例放大模型，你需要找到一个网球场（或者一个差不多大小的地方）。把网球放在球场的一角，然后走到对角的地方把豌豆放在那儿。如果你没法找到网球场，那么把豌豆放在离网球大约25米的地方。这个距离差不多就是质子和电子间距离的等比例放大，因此你可以发现氢原子的内部大部分是空的。其他种类的原子也是如此。如果你拿着网球，让你的朋友拿着豌豆围绕着你跑一个直径大约50米的圆圈，这就代表了电子在氢原子内部所做的运动，虽然它不会像你的朋友一样累得直喘气！



这个氢原子模型的比例尺其实十分粗糙。即使在这个比例下，豌豆也还是有点太大了。不过这个模型强调的是原子内部的大部分空间都是空的。

Now that electrons were known, ingenious experiments revealed their properties. They proved to be responsible for the most significant properties of all of the matter around us. When they break loose from their atoms, electrons can flow as electric currents.

William Crookes (1832–1919) carried out experiments with his tube, which showed that cathode rays consist of something moving from the cathode to the anode. He was able to demonstrate that these objects could exert pressure on obstacles placed in their path. Also, J. J. Thomson (1856–1940) had shown that the objects were probably very small.

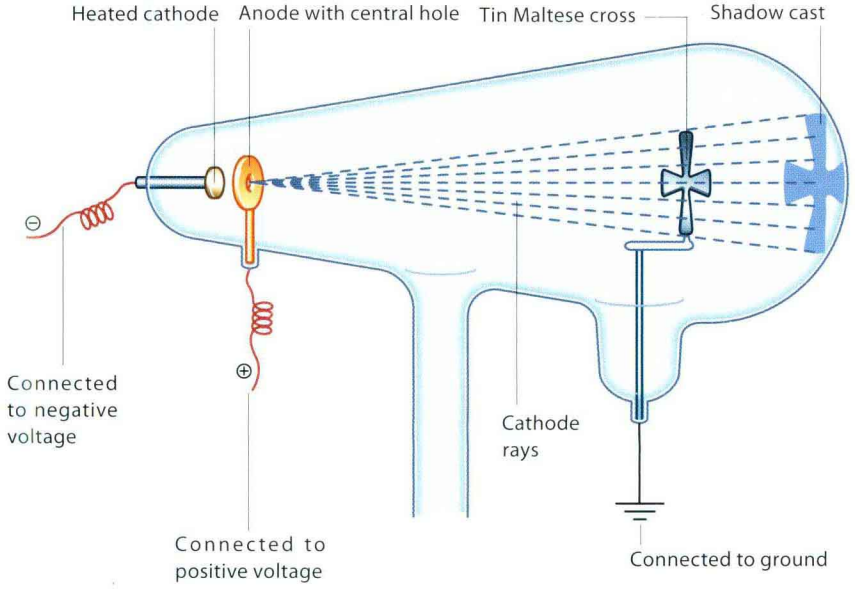
The American physicist Robert Millikan (1868–1953), who measured the charge on the electron in 1909, confirmed these facts. When combined with earlier measurements by Thomson,

WILLIAM CROOKES

By the time Sir William Crookes died in 1919, one of his greatest contributions to science, the Crookes tube, had already been used to create crude images. But he could hardly have dreamed that within a few years of his death it was to become the basis for a whole new technology of communication: television. However, the great scientific importance of the Crookes tube had earned him a knighthood, awarded in 1897. The tube was also used as one of the earliest sources of x-rays. Crookes, born in 1832, was a highly practical person and invented improved methods of making sugar from beet, dyeing textiles, and extracting silver and gold from their ores. He also invented several scientific instruments and publicized the benefits of electric lighting. In 1861, he discovered the metal thallium from the new and unknown pattern of colors in its spectrum and went on to study it.

THE CROOKES TUBE

An air pump reduces the pressure in the glass tube. When a high voltage is applied between the two electrodes (cathode and anode), negatively charged particles move from the cathode (negative electrode) toward the anode (positive electrode). These "cathode rays" overshoot and strike the far end of the tube, making it glow. They cast a shadow if an obstacle is put in their path. (Crookes himself used a thin piece of tin in the shape of a Maltese cross.)



he showed that the mass of the electron was approximately one two-thousandth of the mass of a hydrogen atom.

Physicists now understand what electric currents are. They consist of electrons that have broken free from their atoms and are drifting through, say, a metal wire, or sometimes through space, like the streams of electrons in the Crookes tube. Currents generate heat as the electrons bump into atoms. If they generate enough heat, the temperature of the material rises until it glows—this is what happens in the tungsten filament in an electric light bulb.

Structure of the atom

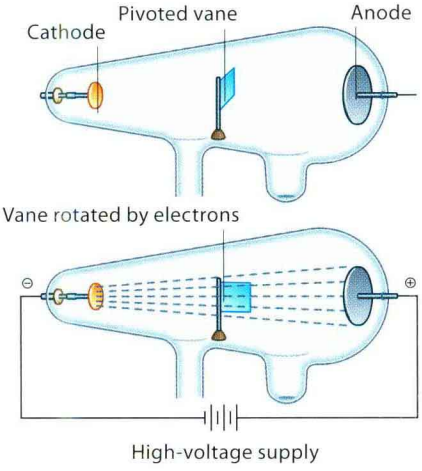
The experiments by Ernest Rutherford (see page 5) had shown that the outer regions of atoms were occupied by electrons, while at the center was the nucleus, positively charged and carrying most of the atom's mass. It was natural to think of the atom as being like a miniature Solar System, with the electrons playing the role of planets and orbiting the central nucleus, which stood for the Sun. The electrons were held in place not by gravity, but by the attraction between their negative charges and the positive charge on the nucleus.

SCIENCE WORDS

- **Crookes tube:** An early experimental vacuum tube in which cathode rays were generated.
- **Electromagnetic radiation:** Energy transmitted through space or a material medium in the form of electromagnetic waves.
- **Electron:** A subatomic particle, found in every atom, that carries negative charge. Most currents consist of electrons in motion.
- **Quantum theory:** Theory based on the idea that light is emitted in separate packets, or quanta (also known as photons).

PRESSURE OF ELECTRONS

In one of the demonstrations that can be carried out with a Crookes tube, a vane that is free to rotate is placed inside it. When a voltage is applied, the vane is pushed around until it is parallel with the stream of cathode rays. This experiment confirms that cathode rays are particles rather than waves.



There was a huge problem with this picture. According to the theories that existed, electrons whirling around within the atom like this should give out all their energy in a brief burst of electromagnetic radiation as they spiraled into the nucleus. All atoms should collapse within a fraction of a second.

In 1912, the Danish physicist Niels Bohr (1885–1962) suggested that electrons can occupy only certain orbits, each orbit having its own definite amount of energy. The only way they can move between orbits is to make an abrupt jump from one to another, giving out or taking in energy, in the form of electromagnetic radiation, in amounts corresponding to the differences in the energy levels of the orbits. Atoms do not collapse because their lowest energy levels are filled with electrons.

From this picture of the atom, scientists gradually developed quantum theory, which is the basis of modern physics.

电子被发现以后，人们又做了许多精巧的实验来探究它的性质。电子被证实与大多数发生在我们身边的事情有着密切的关联。当电子挣脱原子时，它们的流动能够产生电流。

威廉·克鲁克斯（1832—1919）用阴极射线管做过一个实验，证明了阴极射线是由某些从阴极向阳极移动的物质组成的。他成功地验证了这些物质能够在它们路径上的障碍物上产生压力。同时，约瑟夫·约翰·汤姆逊（1856—1940）也证明了这些物质非常微小。

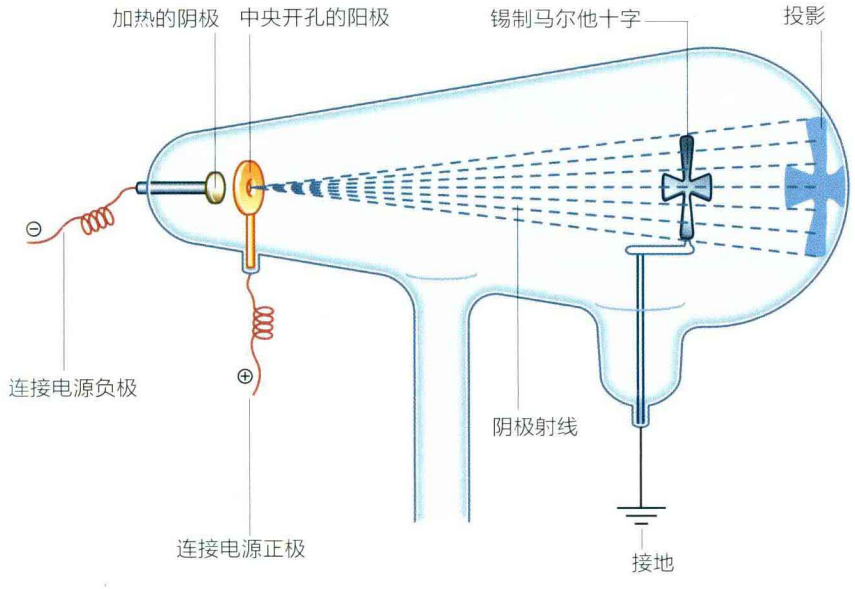
美国物理学家罗伯特·米利肯（1868—1953）在1909年测定了电子上的电荷含量，从而证实了这

威廉·克鲁克斯

当威廉·克鲁克斯在1919年去世时，克鲁克斯管（阴极射线管）早已被用来产生简单的图像。这是他对科学做出的伟大贡献之一。但他也许没想到，在他去世几年后，阴极射线管成为了一项全新科技的基础，这就是电视。不过，阴极射线管的伟大的科学意义也使克鲁克斯在1897年荣获了爵士头衔。阴极射线管也被用作早期的X射线的来源。出生于1832年的克鲁克斯是一个注重实践的人。他改进了从甜菜、纺织品中提取糖的方法和从矿石中提炼金银的方法。他也发明了多种科学仪器并且说明了电气照明的好处。在1861年，他从未知的光谱分布中发现了金属铊。

克鲁克斯管（阴极射线管）

一个气泵用于降低玻璃管内的气压。当两个电极之间有一个高的电压时，带负电的微粒从阴极（负电极）向阳极（正电极）移动。这些“阴极射线”冲过阳极中央的小孔撞击玻璃管的远端，使其发光。当把障碍物（克鲁克斯本人使用的是一小片十字形的锡）放置在它们的路径上时能够产生影子。



些结论。参照汤姆逊早期的实验结果，他证明了电子的质量大约是氢原子的两千分之一。

现在，物理学家们已经发现了电流是怎么产生的。它们由从原子上挣脱的电子组成。当电子流过金属导线或者和阴极射线管一样的空间中时，就会产生电流。电流流过材料时会产生热量，这是因为电子会和材料中的原子发生撞击。如果产生了足够的热量，材料的温度会上升到很高甚至开始发光。我们使用的白炽灯泡就是利用这种原理进行照明的。

原子的结构

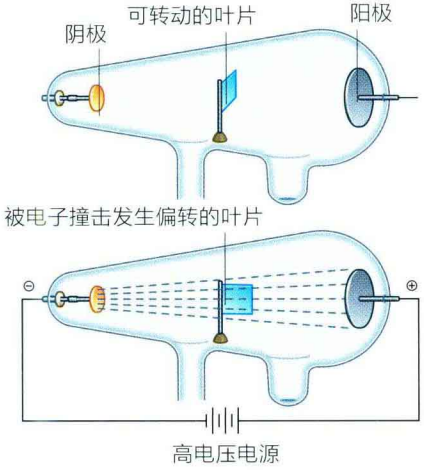
欧尼斯特·卢瑟福的实验证明了电子存在于原子的外层空间中，而原子的中心区域则由原子核占据，原子核带正电并且拥有原子绝大部分的质量。我们可以把原子的结构想象成一个微型太阳系，电子扮演着行星的角色，而原子核扮演着太阳的角色，电子围绕着原子核旋转。与太阳系不同的是，电子并不像行星一样由重力束缚在原子核周围，而是受到电荷之间的相互吸引力。

科学词汇

- **克鲁克斯管（阴极射线管）：**早期的实验设备，是用于产生阴极射线的真空管。
- **电磁辐射：**能量通过电磁波的形式在空间或物质中传播就是电磁辐射。
- **电子：**微小的粒子，存在于所有原子当中，带负电。大部分电流都由运动的电子产生。
- **量子理论：**近代物理学的理论，基本内容是光是一份一份地传播的，即量子（也被称为光子）。

电子的压力

将一个能自由转动的叶片放置在阴极射线管内，当电极通上电压后，叶片会开始转动直到和阴极射线的方向平行。这个实验证明了阴极射线由微小粒子组成而不是由波组成。



但是这个模型有着一个巨大的瑕疵。根据现有的理论，围绕着原子核旋转的电子撞上原子核时会以电磁辐射的方式释放出所有的能量。因此所有的原子都会在1秒内发生崩塌。

1912年，丹麦物理学家尼尔斯·波尔（1885—1962）提出电子只在一些特定的圆形轨道上绕核运行。电子在这些轨道上运行时并不发射能量，只当它从一个较高能量的轨道向一个较低能量的轨道跃迁时才发射电磁辐射，反之吸收电磁辐射。电磁辐射包含的能量由两个轨道间的能量差决定。由于最低能级的轨道上充满着电子，因而原子不会发生崩塌。

根据原子的这种模型，科学家最终推导出量子理论。量子理论是整个现代物理学的基础。

STATIC ELECTRICITY

Electricity is one of the essentials of modern living. It provides us with light, heat, communications, and power. Even ancient peoples knew about electricity—but not the kind you get at the turn of a switch. It was the type of electricity called static electricity, created when an electric charge builds up on an object.

The word "static" means stationary, and static electricity is concerned with stationary electric charges. More than 2,500 years ago, an ancient Greek scientist named Thales of Miletus (*c.*624–*c.*546 B.C.) discovered that when a piece of amber is rubbed with a cloth, it can pick up small pieces of paper, rather like a magnet picks up pins. When 17th-century scientists began to study this effect, they made up the word "electricity" from the Greek word *elektron*, which means "amber." But what exactly is static electricity, and where does it come from?

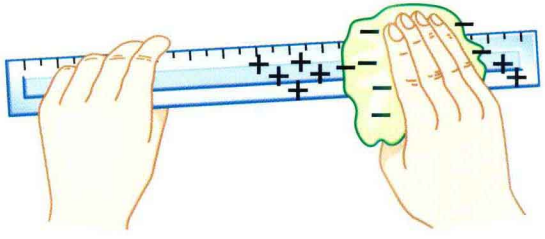
SCIENCE WORDS

- **Charge:** A property of some subatomic particles and some objects that makes them exert forces on one another. There are two types of charge: negative charge and positive charge.
- **Nucleus:** (plural: nuclei) The central part of an atom, consisting of protons and neutrons.
- **Static electricity:** An electric charge on an object that has lost or gained electrons.

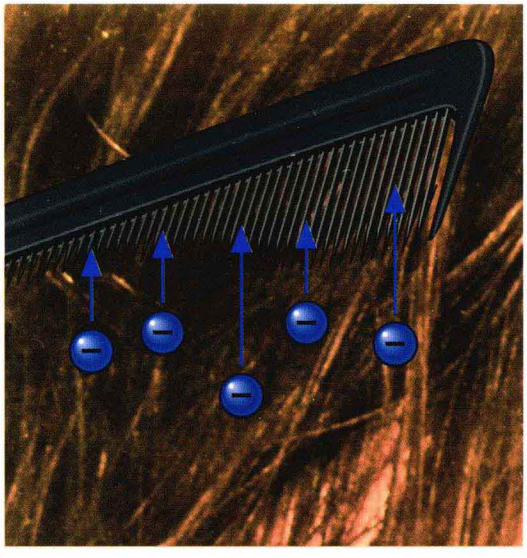
Atomic electricity

Like so many questions in physics, the answer to the last one has to do with atoms. An atom consists of a central nucleus surrounded by one or more electrons. The nucleus

FRICTIONAL ELECTRICITY



Rubbing a plastic ruler with a cloth (above) gives the ruler a charge of positive electricity. The charge arises because electrons are transferred from the ruler to the cloth. The cloth becomes negatively charged.



Human hair (right) works even better than cloth. The friction when you comb your hair about twenty times gives the comb a negative charge. The positively charged hair may stand on end.