Chapter 1

Review

Experimental Physics

Theoretical Physics

Observation

Experiment

Phenomenology

Phenomenological theory

Fundamental Theory

Mathematics
(Mathematical theory

Chapter 1

A Review

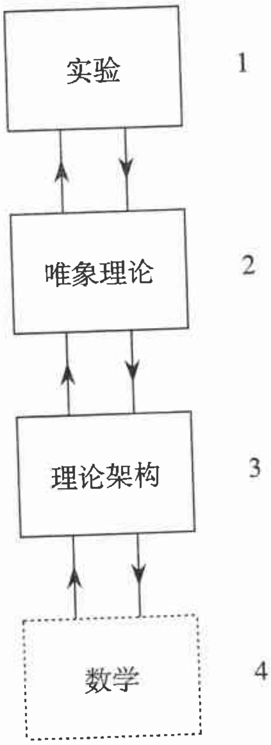
Scientific Method

An overview of the scientific method.

THE SCIENTIFIC METHOD

- An observation is made
- Postulates are developed (as few as possible)
- Physical laws are established
- Language of mathematics is used to develop "equation of motion"
- Observation is explained and predictions are made

Experiments are the final judge

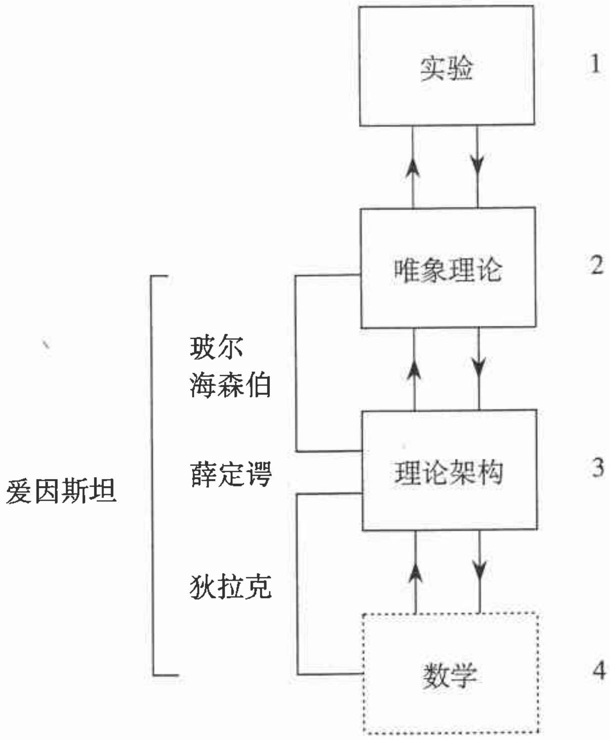


物理学的三个领域

物理学的三个部门和其中的关系：唯象理论（phenomenological theory）（2）是介乎实验（1）和理论架构（3）之间的研究。（1）和（2）合起来是实验物理，（2）和（3）合起来是理论物理，而理论物理的语言是数学。

物理学的发展通常自实验（1）开始，即自研究现象开始。关于这一发展过程，我们可以举很多大大小小的例子。先举牛顿力学的历史为例。布拉赫（T. Brahe，1546—1601）是实验天文物理学家，活动领域是（1）。他做了关于行星轨道的精密观测。后来开普勒（J. Kepler，1571—1630）仔细分析布拉赫的数据，发现了有名的开普勒三大定律。这是唯象理论（2）。最后牛顿创建了牛顿力学与万有引力理论，其基础就是开普勒的三大定律。这是理论架构（3）。

再举一个例子：通过18世纪末、19世纪初的许多电学和磁学的实验（1），安培（A. Ampère，1775—1836）和法拉第（M. Faraday，1791—1867）等人发展出了一些唯象理论（2）。最后由麦克斯韦归纳为有名的麦克斯韦方程（即电磁学方程），才步入理论架构（3）的范畴。



几位 20 世纪物理学家的研究领域

海森伯从实验（1）与唯象理论（2）出发：实验与唯象理论是五光十色、错综复杂的，所以他要摸索，要犹豫，要尝试了再尝试，因此他的文章也就给读者不清楚、有渣滓的感觉。狄拉克则从他对数学的灵感出发：数学的最高境界是结构美，是简洁的逻辑美，因此他的文章也就给读者“秋水文章不染尘”的感受。

让我补充一点关于数学和物理的关系。我曾经把二者的关系表示为两片在茎处重叠的叶片（图 97a. 6）。重叠的地方同时是二者之根，二者之源。譬如微分方程、偏微分方程、希尔伯特空间、黎曼几何和纤维丛等，今天都是二者共用的基本观念。这是惊人的事实，因为首先达到这些观念的物理学家与数学家曾遵循完全不同的路径，完全不同的传统。为什么会殊途同归呢？大家今天没有很好的答案，恐怕永远不会有，因为答案必须牵扯到宇宙观、知识论和宗教信仰等难题。

必须注意的是在重叠的地方，共用的基本观念虽然如此惊人地相同，但是重叠的地方并不多，只占二者各自的极少部分。譬如实验（1）与唯象理论（2）都不在重叠区，而绝大部分的数学工作也在重叠区之外。另外值得注意的是即使在重叠区，虽然基本观念是物理与数学共用，但是二者的价值观与传统截然不同，而二者发展的生命力也各自遵循不同的茎脉流通，如图 97a. 6 所示。

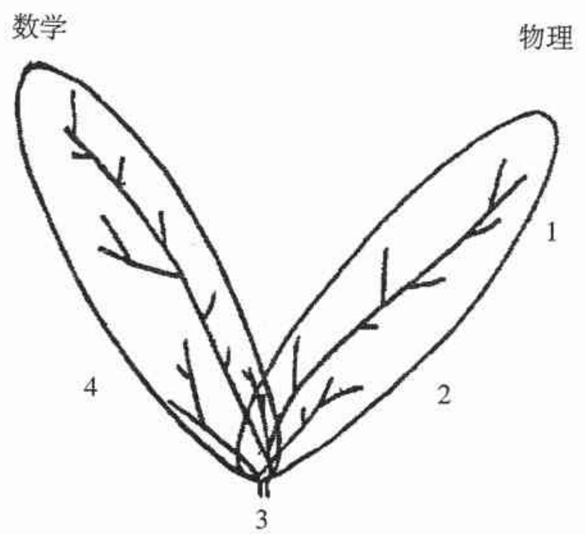


图 97a. 6　二叶图

常常有年轻朋友问我，他应该研究物理，还是研究数学。我的回答是这要看你对哪一个领域里的美和妙有更高的判断能力和更大的喜爱。爱因斯坦在晚年时（1949 年）曾经讨论过为什么他选择了物理。他说[10]：

> 在数学领域里，我的直觉不够，不能辨认哪些是真正重要的研究，哪些只是不重要的题目。而在物理领域里，我很快学到怎样找到基本问题来下工夫。

年轻人面对选择前途方向时，要对自己的喜好与判断能力有正确的自我估价。

Additional
Comments

Definition 定義

Theorem 定理

Law 定律

Mechanics

Coupled harmonic oscillators
normal mode

EM wave

Maxwell equation
EM wave equation
wave propagate in vacuum.

Heinrich Hertz (1857-1894)

Heinrich Hertz

Known for	Electromagnetic radiation Photoelectric effect

Heinrich Hertz

From Wikipedia, the free encyclopedia

Heinrich Rudolf Hertz (22 February 1857 – 1 January 1894) was a German physicist who clarified and expanded James Clerk Maxwell's electromagnetic theory of light, which was first demonstrated by David Edward Hughes using non-rigorous trial and error procedures. Hertz is distinguished from Maxwell and Hughes because he was the first to conclusively prove the existence of electromagnetic waves by engineering instruments to transmit and receive radio pulses using experimental procedures that ruled out all other known wireless phenomena.[1] The scientific unit of frequency — cycles per second — was named the "hertz" in his honor.[2]

In 1883, Hertz took a post as a lecturer in theoretical physics at the University of Kiel.

In 1885, Hertz became a full professor at the University of Karlsruhe where he discovered electromagnetic waves.

The most dramatic prediction of Maxwell's theory of electromagnetism, published in 1865, was the existence of electromagnetic waves moving at the speed of light, and the conclusion that light itself was just such a wave. This challenged experimentalists to generate and detect electromagnetic radiation using some form of electrical apparatus.

The first successful radio transmission was made by David Edward Hughes in 1879, but it would not be conclusively proven to have been electromagnetic waves until the experiments of Heinrich Hertz in 1886. For the Hertz radio wave transmitter, he used a high voltage induction coil, a condenser (capacitor, Leyden jar) and a spark gap—whose poles on either side are formed by spheres of 2 cm radius—to cause a spark discharge between the spark gap's poles oscillating at a frequency determined by the values of the capacitor and the induction coil.

To prove there really was radiation emitted, it had to be detected. Hertz used a piece of copper wire, 1 mm thick, bent into a circle of a diameter of 7.5 cm, with a small brass sphere on one end, and the other end of the wire was pointed, with the point near the sphere. He bought a screw mechanism so that the point could be moved very close to the sphere in a controlled fashion. This "receiver" was designed so that current oscillating back and forth in the wire would have a natural period close to that of the "transmitter" described above. The presence of oscillating charge in the receiver would be signaled by sparks across the (tiny) gap between the point and the sphere (typically, this gap was hundredths of a millimeter).

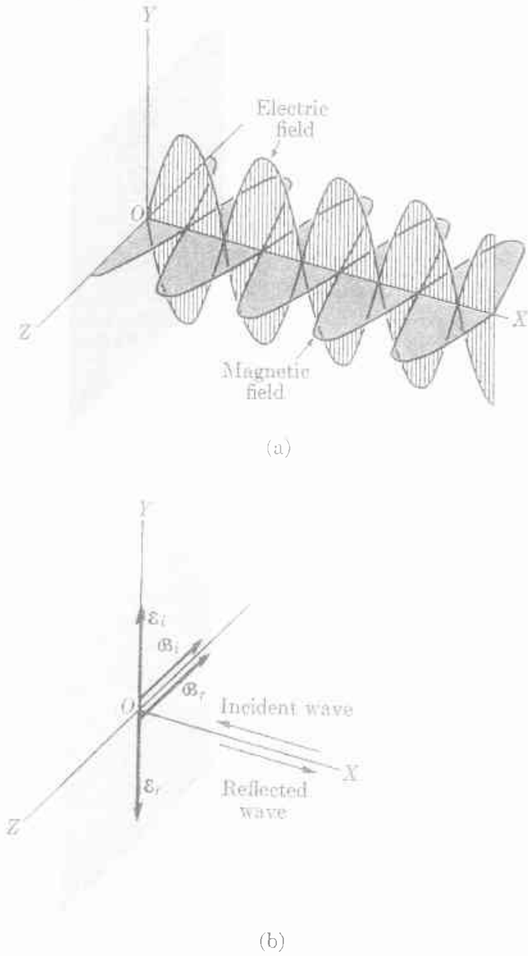
In more advanced experiments, Hertz measured the velocity of electromagnetic radiation and found it to be the same as the light's velocity. He also showed that the nature of radio waves' reflection and refraction was the same as those of light and established beyond any doubt that light is a form of electromagnetic radiation obeying the Maxwell equations.

Hertz's experiments triggered broad interest in radio research that eventually produced commercially successful wireless telegraph, audio radio, and later television. In 1930 the International Electrotechnical Commission (IEC) honored Hertz by naming the unit of frequency—one cycle per second—the "hertz".[2]

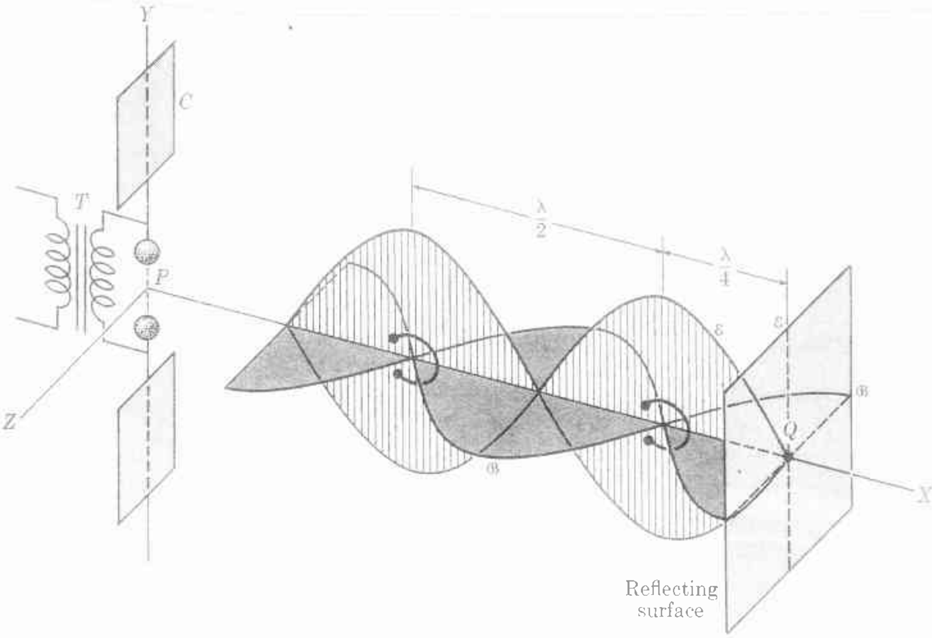
28.5 STANDING ELECTROMAGNETIC WAVES

Interference (and diffraction) phenomena are so characteristic of waves that their presence has always been accepted by physicists as conclusive proof that a process can be interpreted as a wave motion. For that reason, when in the seventeenth century Young, Grimaldi, and others observed interference (and diffraction) in their research on light, the wave theory of light became generally accepted. At that time electromagnetic waves were not known, and light was assumed to be an elastic wave in a subtle medium, called ether, that pervaded all matter. It was not until the end of the nineteenth century that Maxwell predicted the existence of electromagnetic waves, and Hertz, by means of interference experiments which gave rise to standing electromagnetic waves, experimentally verified the existence of electromagnetic waves in the radio-frequency range. Later their velocity was measured and found to be equal to that of light. The reflection, refraction, and polarization of electromagnetic waves was also found to be similar to those of light. The obvious conclusion was to identify light with electromagnetic waves of certain frequencies. At that time optics, to all intents and purposes, ceased to be an independent branch of physics and became simply a chapter of electromagnetic theory.

To understand the formation of standing electromagnetic waves, assume that the waves produced by an oscillating electric dipole are falling with perpendicular incidence on the plane surface of a perfect conductor (Fig. 28.21). Taking the X-axis as the direction of propagation and the Y- and Z-axes as being parallel to the electric and the magnetic fields, respectively, we have a wave that is plane polarized, with the electric field oscillating in the XY-plane. The electric field is then parallel to the surface of the conductor. But at the surface of a perfect conductor the electric field must be perpendicular to the conductor; that is, the electric field cannot have a tangential component. The only way to make this condition compatible with the orientation of the electric field in the incident wave is by requiring that the resultant electric field be zero at the surface of the conductor. This means



28.21 Standing electromagnetic waves produced by reflection from a conducting surface.



Hertz' experiment on interference of electromagnetic waves.

that the electric field of the reflected wave at the surface must be equal and opposite to that of the incident wave, thus giving

$$\mathcal{E} = \mathcal{E}_i + \mathcal{E}_r = 0$$

for $x = 0$. This condition is mathematically equivalent to the condition for the reflection of waves in a string with one end fixed, discussed in Section 28.4. Since the mathematics is the same, we may use Eq. (28.18) to write an expression for the resultant electric field,

$$\mathcal{E} = 2\mathcal{E}_0 \sin kx \sin \omega t.$$

The magnetic field oscillates in the XZ-plane. Using Eq. (24.8), we find that the magnetic field is expressed by

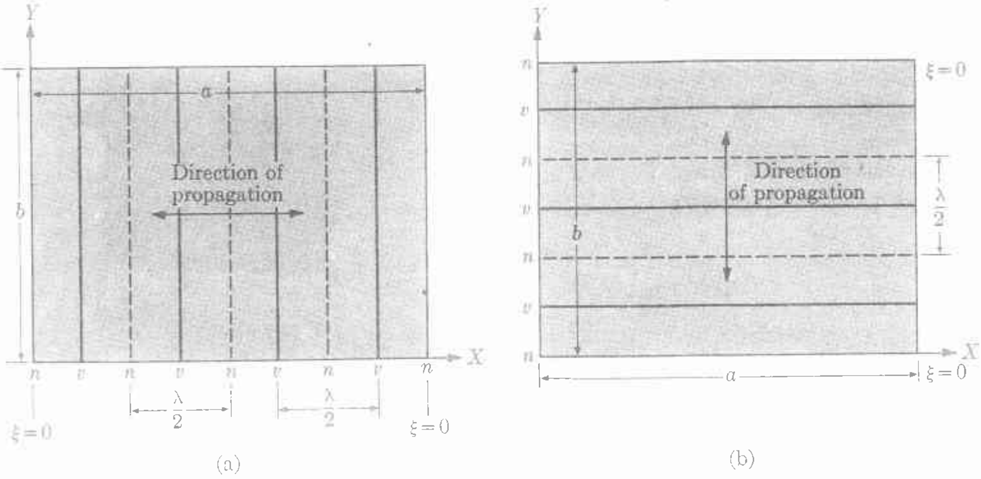
$$\mathcal{B} = 2\mathcal{B}_0 \cos kx \cos \omega t,$$

with $\mathcal{B}_0 = \mathcal{E}_0/c$. Therefore there is a phase difference of $\frac{1}{2}\lambda$ in the space variations and of $\frac{1}{2}P$ in the time variations of the two fields. From the mathematical expression for $\mathcal{B}$, note that the magnetic field has maximum amplitude at the surface. This can also be seen from the boundary condition at the surface: referring to Fig. 28.21(b), we see that if the electric field of the incident wave is along the $+Y$-axis, the magnetic field must be along the $-Z$-axis, according to the relative orientation of the two fields with respect to the direction of propagation of the incident waves, which is along the $-X$-axis. For a zero resultant electric field to exist at the surface, the electric field of the reflected wave must be along the $-Y$-axis, and since the reflected wave propagates along the X-axis, the magnetic field must be along the $-Z$-axis. Thus, although the electric fields interfere destructively at the surface, the magnetic fields interfere constructively there.

The amplitudes of the electric and magnetic fields of the resulting wave at a distance x from the surface are $2\mathcal{E}_0 \sin kx$ and $2\mathcal{B}_0 \cos kx$. They are indicated by the shaded lines in Fig. 28.21(a). At the points where

$$kx = n\pi \qquad \text{or} \qquad x = \tfrac{1}{2}n\lambda,$$

the electric field is zero and the magnetic field is



28.23 Standing waves on a rectangular membrane.

maximum. At the points where

$$kx = (n + \tfrac{1}{2})\pi \qquad \text{or} \qquad x = (2n + 1)\lambda/4,$$

the electric field has a maximum value but the magnetic field is zero.

Hertz' Experiment It is instructive to see how Heinrich Hertz, in 1888, with his primitive equipment, verified the theoretical predictions given above. Hertz' oscillator is shown on the left in Fig. 28.22. The transformer T charges the metallic plates C and C'. These plates discharge through the gap P, which becomes a dipole oscillator. Along the line PX, the direction of the electric field is parallel to the Y-axis and that of the magnetic field along the Z-axis. To observe the waves, Hertz used a short wire, bent in circular shape, but with a small gap. This device is called a *resonator*. The diameter of the resonator used in this kind of experiment must be very small compared with the wavelength of the waves. If the resonator is placed with its plane perpendicular to the magnetic field of the wave, the varying magnetic field induces an emf in the resonator, resulting in sparks at its gap. On the other hand, if the plane of the resonator is parallel to the magnetic field, no emf is induced and no sparks are observed at the gap.

To produce standing electromagnetic waves, Hertz placed a reflecting surface (made of a good conductor) at Q. In such a case, when the resonator is at a node of the magnetic field, no matter what its orientation, it will show no induced emf (or sparks). At an antinode of the magnetic field, however, the sparking is greatest when the resonator is oriented perpendicular to the magnetic field. By moving the resonator along the line PQ, Hertz found the position of the nodes and antinodes and the direction of the magnetic field. The results obtained by Hertz coincided with the theoretical analysis we have given. By measuring the distance between two successive nodes, Hertz could calculate the wavelength λ, and since he knew the frequency ν of the oscillator, he could calculate the velocity c of the electromagnetic waves by using the equation $c = \lambda\nu$. It was by this means that Hertz obtained the first experimental value for the velocity of propagation of electromagnetic waves.