# 1. The Electron

## Electron Charge

Millikan, writing about the electron in 1935, stated, "We knew that there was a smallest thing which took part in chemical reactions and we named that thing the atom, leaving its insides entirely to the future. Precisely similarly the electron was defined as the smallest quantity of electricity which ever was found to appear in electrolysis, and nothing was then said or is now said about its necessary ultimateness. Our experiments have, however, now shown that this quantity is capable of isolation, and that all the kinds of charges which we have been able to investigate are exact multiples of it."

Millikan raised the question, "Is the electron itself divisible?" and discussed the affirmative support put forward from 1914 onwards, principally by Ehrenhaft, only to conclude from an analysis of the experimental evidence that "there has then appeared up to the present time no evidence whatever for the existence of the sub-electron".

At the present time, 1969, we find that physical theories are being developed on the assumption that there are particles of sub-electronic charge. We read about the quarks,* which are hypothetical particles having charges of one third or two thirds that of the electron or positron. A neutron is then imagined to comprise an aggregation of two quarks each of charge $-e/3$ and one quark of charge $+2e/3$, whereas the proton consists of two quarks of $+2e/3$ and one of $-e/3$. Here, $-e$ is the charge of the electron. This is most interesting speculation, but the fact remains that particles with these sub-electronic charges have yet to be discovered. The quarks are purely hypothetical and Millikan's contention that the electron charge is indivisible is not yet disproved by any direct experimental evidence.

## What is an Electron?

Although Millikan stated that the electron was the smallest quantity of electricity ever found to appear in electrolysis and thus characterized the electron by its quantum of charge $-e$, there are other

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* Burhop, 1967. (Note that references are listed on page 217 according to author's name and year of publication.)

elementary particles possessing this unique charge. The electron is further characterized by its small rest mass $m$, known to be about $9 \cdot 1\ 10^{-28}$ gm. The charge $e$ is approximately $4 \cdot 8\ 10^{-10}$ esu, expressed in cgs. units.

Having thus introduced the electron and identified it by its discrete charge $-e$ and discrete rest mass $m$, and shed a little uncertainty on the fundamental quantum nature of the electron charge, we are ready to consider the question, "What is an electron?" Firstly, if it is suggested to some physicists that an electron is a mere corpuscle of electric charge, this evokes a smile and a denial. An electron is not that simple. Some would present the electron as a kind of vector symbol. Others present it as a mathematical formulation. They have in mind the spin properties of the electron, or its wave characteristics, and they are not really answering the question "What is an electron?", but the question of how an electron manifests itself. Yet, its behaviour really depends upon its interaction with something else, be it only the observer! Then, we see that we might have mixed the electron up with the properties of something else. According to Heisenberg's Principle of Uncertainty, as quoted by Eddington (1929, a) "A particle may have position or it may have velocity but it cannot in any exact sense have both." Is Eddington really suggesting that a particle cannot have a position and a motion at the same time, or is he saying that our powers of observation are limited and preclude us from determining the exact position and velocity of the particle at any instant? It is submitted that the electron is not a mathematical symbol, nor is it a wave or group of waves. An electron is an elementary particle, almost by definition, and must be taken to be a corpuscle in any serious attempt to understand what it really is, meaning its size, shape and content. It can be asked why the real nature of the electron matters when physical theory need only be concerned with its behaviour as seen by an observer. The answer to this is that the electron presumably will still exist even when the observer is removed. Its properties cannot, therefore, be wholly related to the existence of the observer. The electron will still interact with other matter, and its interaction properties could well account for certain physical phenomena as yet unexplained in physical theory.

## The Electron in Motion

Assuming the well known relation $E = Mc^2$ and that there is no loss of energy by radiation or otherwise when a particle of mass $M$ is accelerated to acquire kinetic energy itself augmenting the energy $E$, it may be shown that the mass of a particle increases to infinity as the particle approaches the limiting velocity $c$. The applicable formula for the mass of the particle when moving at velocity $v$ is given by:

$$M = M_0/\sqrt{[1-(v/c)^2]} \tag{1.1}$$

where $M_0$ is the mass of the particle when at rest.* The velocity $c$ is the speed of light in vacuo.

Wilson (1946), after presenting the above result, writes "If the particle considered is an electron, $M$ will be the mass of the electromagnetic field which it excites and which moves along with it, together with any additional mass which it may have. If the electron is merely an electric charge, it may have no additional mass, but if it has some internal energy besides its electrical energy, it will have some additional mass corresponding to this additional energy. In any case its mass should vary with its velocity in accordance with the expression found above for $M$, since this should hold for a particle of any kind. The experiments of Kaufmann, Bucherer and others on the variation of the mass of electrons with their velocity have shown that the mass does vary approximately in accordance with the above formula. These experiments confirm the idea that momentum is due to flux of energy, but they give no information as to the constitution of electrons."

Experiments on the increase of electron mass with velocity do, however, show that electron charge does not vary with velocity. It is mass which varies. The analysis used to derive equation (1.1) also suggests that an electron does not dissipate its energy by radiation when it is accelerated and this is a most important point to keep in mind because this is in conflict with other currently accepted theory.

## X-ray Scattering by Electrons

The role of electrons in X-ray scattering has been analysed by A. H. Compton. It is found that the wave-length of the scattered rays is not the same as that of the incident rays. Compton supposed that when a photon, as an incident radiation quantum, is intercepted by an electron, a photon quantum of scattered radiation of lower frequency is produced. Then, by assuming that both energy and momentum are conserved, results in conformity with observation are obtained. Since

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* The mathematical proof of this is presented in a later section of this chapter.

Compton only considers the electron's kinetic energy, this means that the energy supplied to the electron in this scattering process is wholly kinetic. Now, the electron has a charge and its velocity is changed when it absorbs momentum. Its magnetic field must therefore change and with this the magnetic field energy must change. Yet, as just stated, experiment shows that the energy form which is changed is wholly kinetic.

This result is, of course, compatible with the above theoretical explanation of the increase in mass with velocity. Magnetic energy must, presumably, be the whole or part of the kinetic energy itself. It is the implications of this which guide us to understand more about the real nature of the electron.

## Magnetic Energy of the Electron

The magnetic energy of an electron in motion is easily calculated if the electron of charge $-e$ can be regarded as a sphere of radius $R$ with the magnetic field energy wholly disposed outside the sphere. The field $H$ distant $x$ from a charge $e$ moving at velocity $v$ at an angle $\theta$ to the $x$ distance vector is:

$$H=(ev/c)\sin\theta/x^2 \tag{1.2}$$

This can be used in the following expression for the magnetic energy.

$$E=\int_{\theta=0}^{\pi}\int_{x=0}^{\infty}(H^2/8\pi)2\pi x\sin\theta\, x\,dx\,d\theta \tag{1.3}$$

Upon evaluation using (1.2) and (1.3), we find:

$$E=e^2v^2/3Rc^2 \tag{1.4}$$

Nissim (1966), in reviewing the electromagnetic mass properties of this electron, writes: "Thus, by virtue of its electromagnetic field energy, an electron possesses an electromagnetic mass equivalent to $2e^2/3Rc^2$. This was held by J. J. Thomson to be in addition to the 'ordinary' mechanical mass of the electron but, as previously mentioned, Abraham and others subsequently advanced the hypothesis that the electromagnetic mass, or self-mass as it has been called, represents the total inertial mass of the electron. . . . Relativistic considerations, however, have caused physicists to abandon this idea and veer to the view that the electron possesses a certain mechanical inert mass in addition to an electromagnetic mass."

## Electrostatic Rest Mass Energy of Electron

If an electron is a charged sphere and the charge is taken to be uniformly spread over its surface of radius $R$, the intrinsic electric field energy is $e^2/2R$, corresponding to a rest mass of $e^2/2Rc^2$, which is less than the electromagnetic mass just deduced. To resolve this difficulty, we may follow the argument of Wilson (1946) that there are binding forces restraining the electron charge from expanding and these must also represent an energy term. He calculated the binding energy for the spherical shell electron model as $e^2/6R$, which exactly balances the discrepancy between the electric and magnetic rest mass calculations.

Alternatively, if an electron is regarded as constrained to occupy a fixed volume, it will be found to adopt spherical form for minimum electric field energy and, for uniform pressure throughout this volume, its charge will be so distributed that its total electric field energy becomes $2e^2/3R$. This again leads to equality in the rest mass calculations, allowing kinetic energy to be identified with magnetic energy. A proof of this is given in Appendix I.

This may seem to be mere speculation. If an electron is a sphere of charge, it must have a certain size and therefore a certain rest energy. There must be something holding it together, whether it is spherical or not. In established physical theory these facts cannot be avoided; they are implicit in our analysis of electron behaviour. Instead of assuming a quantized charge and a quantized rest energy, which is too easy a way of avoiding the problem, we may note that, although charge does not vary with velocity, energy does vary with velocity. Then we can consider assigning a quantum volume of space to the electron. Why not quantize space rather than energy? This volume will not have to change with velocity and the fact that it is constant accounts in a single assumption for rest mass energy quantization and for the binding force action restraining charge expansion, thus simplifying the model of the electron.*

## Electric Field Induction by Motion of Electric Charge

When an electric charge is in motion at a steady velocity, its electric field moves bodily with it. According to the principles of Relativity,

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* The theory of quantum space has remarkable impact upon the understanding of elementary particles. See Chapter 7.

if an observer moves at this same steady velocity, he will not be able to detect any effects of the motion. If the velocity is measured relative to the observer, then the electron will induce the magnetic field just considered and, presumably, the energy of this field will account for its mass properties. However, will any electric field effect of a dynamic character also be induced? A single classical line of reasoning suggests that there is an electric dynamic field effect.

Referring to Fig. 1.1, consider a charge $e$ located at $O$ to be moving with a velocity $v$, as shown. At a point $P$, the strength of the field from $e$ is $e/x^2$. Also at $P$, the electric charge $e$ is really "seen" by an observer to be at $Q$ because the disturbance set up by the charge in motion past $P$ is propagated at the finite velocity $c$. There must, therefore, be an electric displacement at $P$, denoted $V$. The position of $Q$ is found from the relationship:

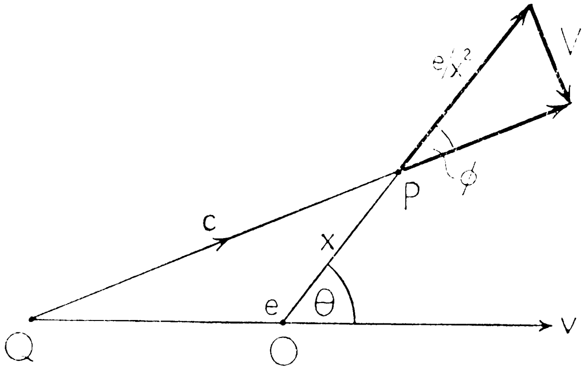

Fig. 1.1

$$QP/QO = c/v \tag{1.5}$$

because the charge travels from $Q$ to $O$ in the time taken for the disturbance to travel from $Q$ to $P$. When $V$ is added vectorially to the radial field $e/x^2$ from $O$ to $P$, the resultant vector lies along $QP$. Further, since the displacement field will be in the direction needed for least energy, that is minimum $V$, this vector $V$ will be normal to the radial field direction $QP$. It follows that $V$ is given by:

$$V = (e/x^2) \sin \varphi \tag{1.6}$$

Now, $\varphi$ is the angle between $QP$ and $OP$ and if $\theta$ is the angle between $QO$ and $OP$

$$QO \sin \theta = QP \sin \varphi \tag{1.7}$$

From (1.5), (1.6) and (1.7):

$$V = (ev/c) \sin \theta / x^2 \tag{1.8}$$

By analogy with equation (1.2), we find that the electric energy attributable to this is exactly as given by equation (1.4). Thus, the dynamic electric field energy is:

$$E = e^2 v^2 / 3Rc^2 \tag{1.9}$$

Curiously, the magnetic field energy density and electric field energy density due to the motion of the charge are identical everywhere in the field.

Now, this poses a problem. If magnetic energy is wholly identified with the kinetic energy, how can we now explain an additional component of dynamic energy which is exactly equal to the magnetic energy? This analysis draws attention to an anomaly facing the observations from the Compton Effect.

## Is Magnetic Energy Negative?

It is standard in physical theory to write the magnetic energy density of a field $H$ as $H^2/8\pi$. However, it is equally standard to put a minus sign in front of magnetic energy terms when energy balance conditions are under study. According to Bates (1951, a): "The minus sign merely indicates that we have to supply heat in order to destroy the intrinsic magnetization." Put another way, since heat is really kinetic energy, we can say that:

$$\text{Kinetic energy} - \text{magnetic energy} = 0$$

However, this does not read kinetic energy equals magnetic energy, meaning that they are identical. It reads that when we have kinetic energy and magnetic energy together in equal measure, they constitute no overall energy whatsoever.

If this applies to the electron, we see that the total of the kinetic energy and the magnetic energy is zero, but since there is also a dynamic electric energy equal to either quantity, the net dynamic energy of the electron is given by equation (1.9) alone.

It follows that we really should take the experimental evidence afforded by the Compton Effect as a clear indication that kinetic energy, magnetic energy and dynamic electric energy exist in equal measure when an electron is in motion but that since one of these, To advance to the next page press PPPPP