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from an equal charge in vacuum, repels it with a force of 8.9874×10^9 *newtons*. Formula (14.3) holds only for two charged particles in vacuum; that is, for two charged particles in the absence of any other charge or matter (see Section 16.6). Note that, according to Eq. (14.2), we express K_e in N m^2 C^{-2} or m^3 kg s^{-2} C^{-2}.

For practical and computational reasons, it is more convenient to express K_e in the form

$$K_e = \frac{1}{4\pi\epsilon_0}, \tag{14.4}$$

where the new physical constant ϵ_0 is called the *vacuum permittivity*. According to the value assigned to K_e, it has the value

$$\epsilon_0 = \frac{10^7}{4\pi c^2} = 8.854 \times 10^{-12}\ \mathrm{N^{-1}\,m^{-2}\,C^2} \quad \text{or} \quad \mathrm{m^{-3}\,kg^{-1}\,s^2\,C^2}. \tag{14.5}$$

Accordingly, we shall normally write Eq. (14.3) in the form

$$F = \frac{qq'}{4\pi\epsilon_0 r^2}. \tag{14.6}$$

When using Eq. (14.6), we must include the charges q and q' with their signs. A negative value of F corresponds to attraction and a positive value corresponds to repulsion.

EXAMPLE 14.1 Given the charge arrangement of Fig. 14–6, where $q_1 = +1.5 \times 10^{-3}$ C, $q_2 = -0.5 \times 10^{-3}$ C, $q_3 = 0.2 \times 10^{-3}$ C, and $AC = 1.2$ m, $BC = 0.5$ m, find the resultant force on charge q_3.

Solution: The force F_1 between q_1 and q_3 is repulsive, while the force F_2 between q_2 and q_3 is attractive. Their respective values, when we use Eq. (14.6), are

$$F_1 = \frac{q_1 q_3}{4\pi\epsilon_0 r_1^2} = 1.875 \times 10^3\ \mathrm{N}, \qquad F_2 = \frac{q_2 q_3}{4\pi\epsilon_0 r_2^2} = -3.6 \times 10^3\ \mathrm{N}.$$

Therefore the resultant force is

$$F = \sqrt{F_1^2 + F_2^2} = 4.06 \times 10^3\ \mathrm{N}.$$

14.4 Electric Field 442-(447) Obs; boldface letters denote vectors.

Any region where an electric charge experiences a force is called an *electric field*. The force is due to the presence of other charges in that region. For example, a charge q placed in a region where there are other charges q_1, q_2, q_3, etc. (Fig. 14–7) experiences a force $\boldsymbol{F} = \boldsymbol{F}_1 + \boldsymbol{F}_2 + \boldsymbol{F}_3 + \cdots$, and we say that it is in an electric field produced by the charges $q_1, q_2, q_3, \ldots$ (The charge q of course also exerts forces on $q_1, q_2, q_3, \ldots$, but we are not concerned with them now.) Since the force that each charge $q_1, q_2, q_3, \ldots$ produces on the charge q is proportional to q, the

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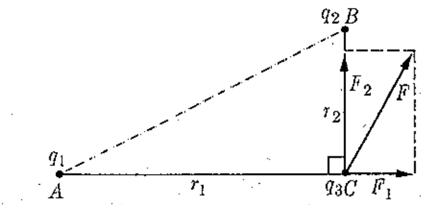

Fig. 14–6. Resultant electric force on q_3 due to q_1 and q_2

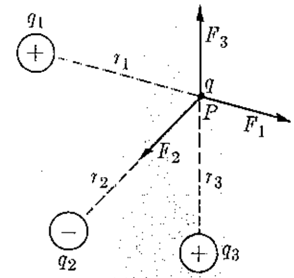

Fig. 14–7. Resultant electric field at P produced by several charges

resultant force F is also proportional to q. Thus the force on a particle placed in an electric field is proportional to the charge of the particle. fig 14.7 above

The *intensity of the electric field* at a point is equal to the force per unit charge placed at that point. The symbol is $\mathcal{E}$. Therefore

$$\mathcal{E} = \frac{\boldsymbol{F}}{q} \qquad \text{or} \qquad \boldsymbol{F} = q\mathcal{E}. \tag{14.7}$$

The electric field intensity $\mathcal{E}$ is expressed in newtons/coulomb or N C^{-1}, or, using the fundamental units, m kg s^{-2} C^{-1}.

Note that, in view of the definition (14.7), if q is positive, the force $\boldsymbol{F}$ acting on the charge has the same direction as the field $\mathcal{E}$, but if q is negative, the force $\boldsymbol{F}$ has the direction opposite to $\mathcal{E}$ (Fig. 14–8). Therefore if we apply an electric field to a region where positive and negative particles or ions are present, the field will tend to move the positively and negatively charged bodies in opposite directions, resulting in a charge separation, an effect sometimes called *polarization*.

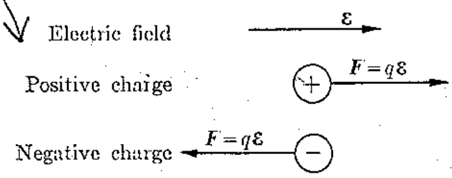

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Fig. 14–8. Direction of the force produced by an electric field on a positive and a negative charge.

Let us write Eq. (14.6) in the form $F = q'(q/4\pi\epsilon_0 r^2)$. This gives the force produced by the charge q on the charge q' placed a distance r from q. We may also say, using Eq. (14.7), that the electric field $\mathcal{E}$ at the point where q' is placed is such that $F = q'\mathcal{E}$. Therefore, by comparing both expressions of F, we conclude that the electric field at a distance r from a point charge q is $\mathcal{E} = q/4\pi\epsilon_0 r^2$, or in vector form,

$$\mathcal{E} = \frac{q}{4\pi\epsilon_0 r^2}\,\boldsymbol{u}_r, \tag{14.8}$$

where $\boldsymbol{u}_r$ is the unit vector in the radial direction, away from the charge q, since $\boldsymbol{F}$ is along this direction. Expression (14.8) is valid both for positive and negative (p444) Comm

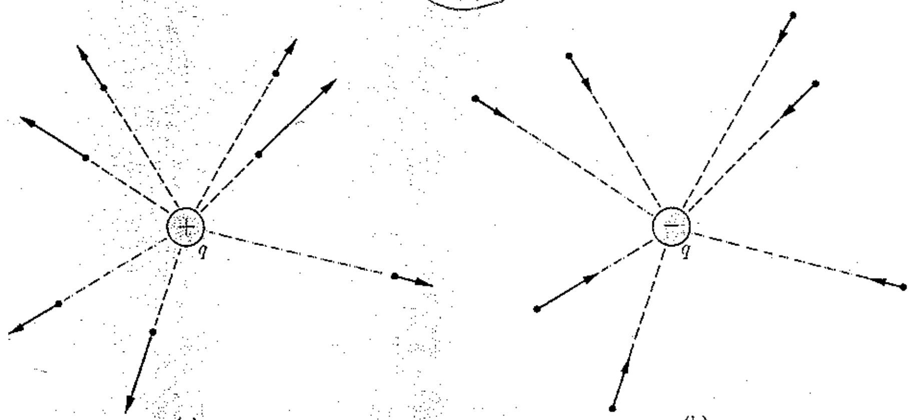

Fig. 14–9. Electric field produced by a positive and a negative charge.

charges, with the direction of $\mathcal{E}$ relative to u_r given by the sign of q. Thus $\mathcal{E}$ is directed away from a positive charge and toward a negative charge. In the corresponding formula for the gravitational field (Eq. 13.15), the negative sign was written explicitly because the gravitational interaction is always attractive. Figure 14–9(a) indicates the electric field near a positive charge, and Fig. 14–9(b) shows the electric field near a negative charge. fig 14.9 a & b above

Just as in the case of a gravitational field, an electric field may be represented by lines of force, which are lines that, at each point, are tangent to the direction of the electric field at the point. The lines of force in Fig. 14–10(a) depict the electric field of a positive charge, and those in Fig. 14–10(b) show the electric field of a negative charge. They are straight lines passing through the charge.

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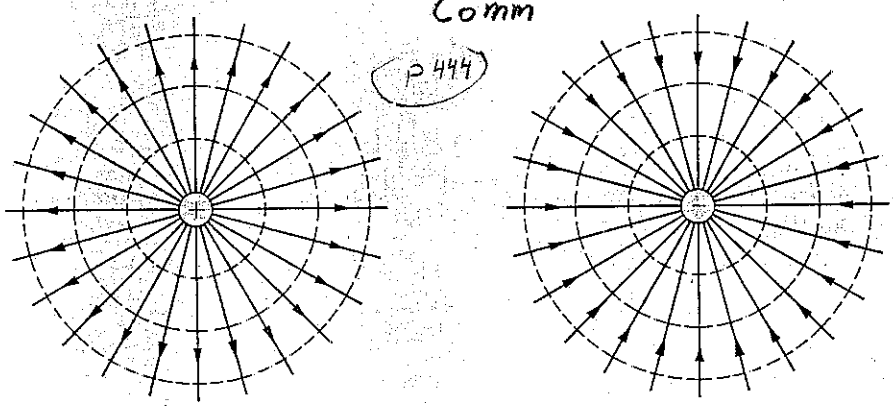

Fig. 14–10. Lines of force and equipotential surfaces of the electric field of a positive and a negative charge.

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