in the apparatus at will. Millikan reported that in some cases he was able to observe a given oil drop for up to six hours and that the drop changed its charge several times.

Measurement of electron charge

Millikan made thousands of measurements using different oils and showed that there is a basic quantized electron charge. Millikan's value of e was very close to our presently accepted value of 1.602×10^{-19} C. Notice that we always quote a positive number for the charge e. The charge on an electron is then $-e$.

from Modern Physics 2e by Thorton and Rex

Example 3.2

For an undergraduate physics laboratory experiment we often make two changes in Millikan's procedure. First, we use plastic balls of about 1 micrometer (μm or micron) in diameter, for which we can measure the mass easily and accurately. This avoids the measurement of the oil drop's terminal velocity and the dependence on Stokes's law. The small plastic balls are still sprayed through an atomizer in liquid solution, but the liquid soon evaporates in air. The plastic balls are easily seen by a microscope. One other improvement is to bombard the region between the plates occasionally with ionizing radiation (such as x rays or α particles from radioactive sources). This radiation ionizes the air and makes it easier for the charge on a ball to change. By making many measurements we can determine whether the charges determined from Equation (3.8) are multiples of some basic charge unit.

One problem in the experiment is that occasionally one obtains fragments of broken balls or clusters of several balls. These can be eliminated by watching the flight of balls in free fall. The majority of balls will be single and fall faster than fragments, but slower than clusters. With a little experience one can select single unbroken balls.

In an actual undergraduate laboratory experiment the mass of the balls was $m = 5.7 \times 10^{-16}$ kg and the spacing eween the plates was $d = 4$ mm. Therefore q can be found from Equation (3.8).

$$q = \frac{mgd}{V} = \frac{(5.7 \times 10^{-16}\ \text{kg})(9.8\ \text{m/s}^2)(4 \times 10^{-3}\ \text{m})}{V}$$

$$q = \frac{(2.23 \times 10^{-17}\ \text{V})}{V}\text{C}$$

where V is the voltage between plates when the observed ball is stationary. Two students observed 30 balls and found the values of V shown in Table 3.1 for a stationary ball. In this experiment the voltage polarity can easily be changed, and a positive voltage represents a ball with a positive charge. Notice that charges of both signs are observed.

The values of $|q|$ are plotted on a histogram in units of $\Delta q = 0.2 \times 10^{-19}$ C. These are shown by the solid area in Figure 3.5. When 70 additional measurements from other students are added, a clear pattern of quantization develops with a charge $q = nq_0$, especially for the first three groups. The groups become increasingly smeared out for higher charges. The areas of the histogram can be separated for the various n values, and the value of q_0 found for each measurement is then averaged. For the histogram shown we find $q_0 = 1.7 \times 10^{-19}$ C for the first 30 measurements and $q_0 = 1.6 \times 10^{-19}$ C for all 100 observations.

TABLE 3.1
Student Measurements in Millikan Experiment

Particle	Voltage (V)	$q(\times 10^{-19}\ \text{C})$	Particle	Voltage	q	Particle	Voltage	q
1	−30.0	−7.43	11	−126.3	−1.77	21	−31.5	−7.08
2	+28.8	+7.74	12	−83.9	−2.66	22	−66.8	−3.34
3	−28.4	−7.85	13	−44.6	−5.00	23	+41.5	+5.37
4	+30.6	+7.29	14	−65.5	−3.40	24	−34.8	−6.41
5	−136.2	−1.64	15	−139.1	−1.60	25	−44.3	−5.03
6	−134.3	−1.66	16	−64.5	−3.46	26	−143.6	−1.55
7	+82.2	+2.71	17	−28.7	−7.77	27	+77.2	+2.89
8	+28.7	+7.77	18	−30.7	−7.26	28	−39.9	−5.59
9	−39.9	−5.59	19	+32.8	+6.80	29	−57.9	−3.85
10	+54.3	+4.11	20	−140.8	+1.58	30	+42.3	+5.27

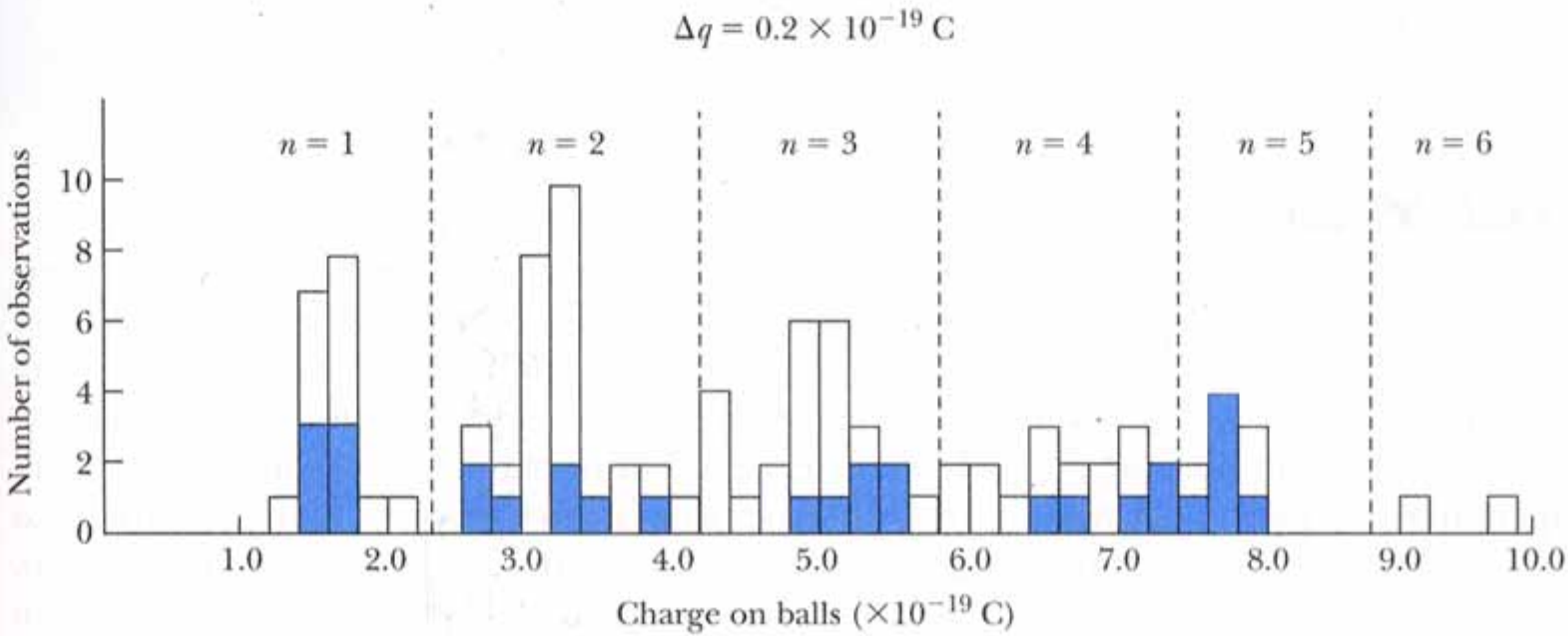

FIGURE 3.5 A histogram of the number of observations for the charge on a ball in a student Millikan experiment. The histogram is plotted for $\Delta q = 0.2 \times 10^{-19}$ C. The solid area refers to the first group's 30 measurements, and the open area to another 70 measurements. Notice the peaks, especially for the first three ($n = 1, 2, 3$) groups, indicating the electron charge quantization. When the basic charge q_0 is found from $q = nq_0$ (n = integer), $q_0 = 1.6 \times 10^{-19}$ C was determined in this experiment from all 100 observations.