Ionization chambers

Free-air ion chambers

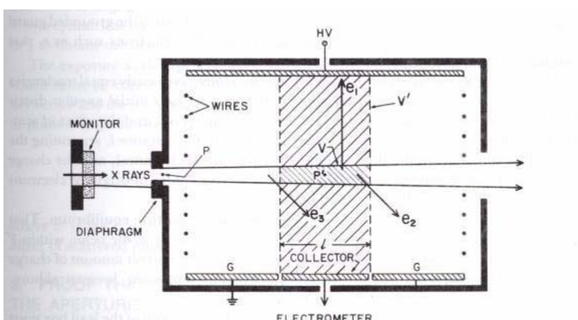
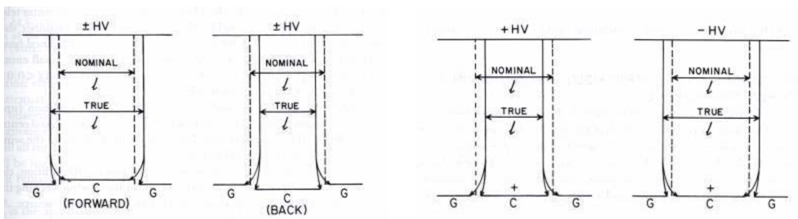


FIGURE 12.1. Schematic plan view of a typical standard free-air ionization chamber. The x-ray beam passes midway between the high-voltage plate and the co-planar guard (G) and collector plates, operated at ground potential. The x-ray beam enters the chamber through a tungsten-alloy diaphragm with an aperture area A_0. The ionization desired for an exposure measurement is that produced by the electrons originating in volume V. The measured ionization is that collected from volume V'. CPE for volume V' makes the two ionizations equal.

$$X = \frac{Q}{m} e^{\mu x'} = \frac{Q}{l A_0 \rho} e^{\mu x'}$$

Causes of electric-field distortion in parallel plate chambers



Cavity ionization chambers

1. They can be made very compact, even for high-energy use, since the range of the secondary electrons in the solid wall material is only $\sim 10^{-3}$ as great as in atmospheric air.
2. They can measure multidirectional radiation fields, while free-air chambers require nearly monodirectional beams aligned to pass perpendicularly through the aperture.
3. Through the application of cavity theory (Chapter 10), the absorbed dose can be determined in any material of which the cavity wall is made.
4. Cavity chambers are capable of great variety in design, to permit dose measurements of charged particles and neutrons as well as photons. Free-air chambers are designed exclusively for x rays, mainly below 300 keV, and do not lend themselves to modification for other kinds of radiation.
5. Gas cavities can be designed to be thin and flat to measure the dose at the surface of a phantom and its variation as a function of depth, or can be made very small to function as a probe to sample the dose at various points in a medium under irradiation.
6. Collected charge can be measured in real time by connecting the chamber to an electrometer, or the chamber can be operated without cables if it is a condenser-type cavity chamber.

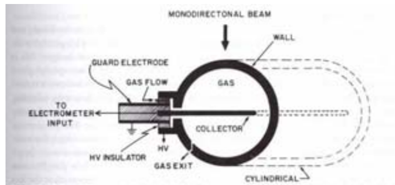
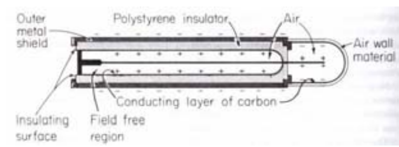


FIGURE 12.9. Fully guarded spherical thimble-type cavity ionization chamber. Cylindrical types may be regarded as elongated spherical chambers.



Flat cavity Chambers: Extrapolation Chambers

1. They can be constructed with thin foils or plastic membranes for one or both of the flat walls, causing only minimal attenuation or scattering of incident electrons or soft x-rays.
2. The gas layer can be made as thin as ≅0.5 mm, allowing sampling of the dose with good depth resolution, especially advantageous in regions where the dose changes rapidly with distance.
3. In some designs the thickness of the gas layer is made variable, for example by an adjustable screw, thus allowing extrapolation of the ionization per unit gas-layer thickness to zero thickness. This in effect removes the influence of perturbation due to the presence of a finite cavity in a phantom, for example, and further increases resolution of dose vs. depth.
4. The dose at the surface of a phantom can be measured by extrapolation (Velkley et al., 1975), and the buildup vs. depth can be observed by adding thin sheets of phantom medium over the entrance foil.

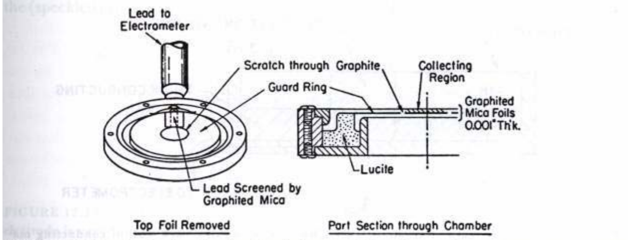


FIGURE 12.11. Ionization chamber for dosimetry of fast-electron beams (Boag, 1966. Reproduced with permission of J. W. Boag and Academic Press.)

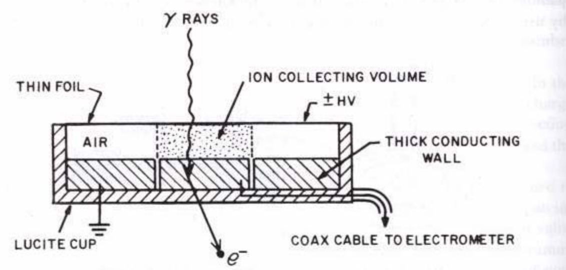


FIGURE 12.12. Schematic diagram of a flat chamber with thick back wall of conducting material, illustrating the cause of polarity differences observed in the measured output current resulting from γ radiation.

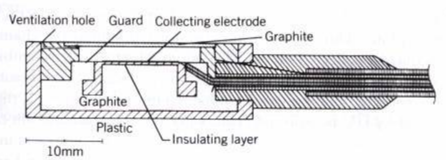


FIGURE 12.13. Flat chamber designed not to exhibit polarity-difference effects. The collecting electrode is very thin (<0.1 mm) and is mounted on a thin insulating layer ($\cong 0.2$ mm). (Mattsson, et al., 1981. Reproduced with permission from L. O. Mattsson and *Acta Radiologica Oncologie*.)

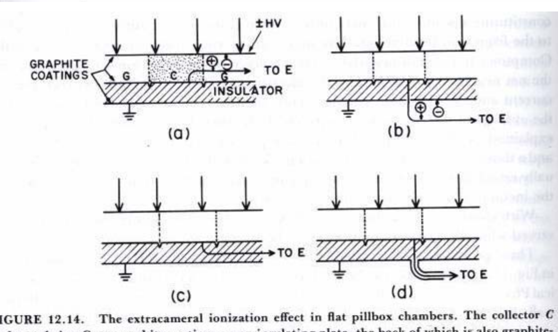


FIGURE 12.14. The extracameral ionization effect in flat pillbox chambers. The collector *C* and guard ring *G* are graphite coatings on an insulating plate, the back of which is also graphite-coated and grounded. (*a*) Bare wire connects collector to a coax cable, thence to the electrometer; (*b*) bare wire out the back; (*c*) wire buried in insulating plate; (*d*) coaxial cable all the way to the electrometer. (See text.)

Transmission Monitor Chambers

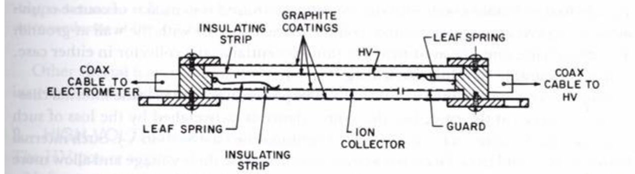


FIGURE 12.15. Simple design for a transmission ionization chamber. The size is optional, but the HV electrode should be larger in diameter than the ion collector, which in turn should cover the beam area to be monitored. (See text.)

Atmospheric Corrections

$$\rho = \rho_{0,760} \left[\frac{273}{273 + T(°\mathrm{C})} \cdot \frac{P - 0.3783\ P_w}{760} \right]$$

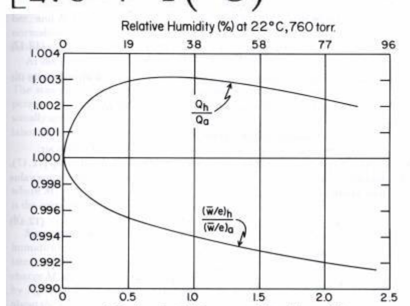


FIGURE 12.20. *Upper curve:* Ratio of the ionization Q_h produced in humid air to that (Q_a) produced in dry air, for a constant B–G cavity chamber volume, temperature, and total pressure, as a function of relative partial pressure of water vapor (bottom scale) or relative humidity (top scale). *Lower curve:* The ratio of $(\overline{W}/e)_h$ for humid air to $(\overline{W}/e)_a = 33.97$ J/C for dry air.

Correction of a charge or current measured due to P and T changes

No humidity correction at the calibration lab

$$M = M' \left(\frac{760}{P} \cdot \frac{273 + T(°C)}{273 + 22} \right)$$

$$M = M' \left(\frac{760}{P} \cdot \frac{273 + T(°C)}{273 + 22} \right) \cdot \left(\frac{Q_a}{Q_h} \right)$$

Ion chamber saturation and recombination

$$D = \frac{Q}{\rho V} \cdot \frac{\overline{W}}{e}$$

a. electrical breakdown of insulators, or

b. gas multiplication, in which the free electrons gain enough kinetic energy from the electrical field within their mean free path in the gas to ionize the next atom they encounter. Thus extra ionization, not due to the ionizing radiation field, is produced. This is desired in proportional and Geiger–Müller counters, but not in ionization chambers.

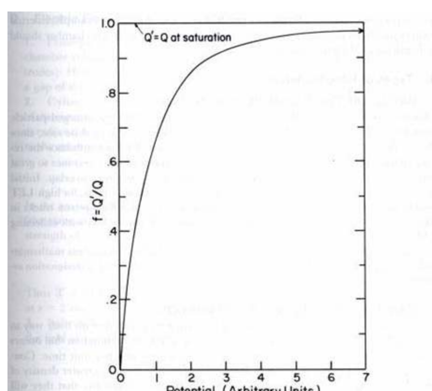


FIGURE 12.21. Variation of ionization charge Q' collected from an ion chamber vs. applied potential. Q is the charge produced by radiation.

Types of Recombination

1. **Initial or columnar recombination**
2. **General or volume recombination**

E. Boag's Treatment of Mie's Theory of General or Volume Recombination for Constant Dose Rate in an Electronegative Gas such as Air

$$\frac{1}{Q'} = \frac{1}{Q} + \frac{m^2 d^4}{6vt} \cdot \frac{1}{P^2} = \frac{1}{Q} + \frac{c}{P^2}$$

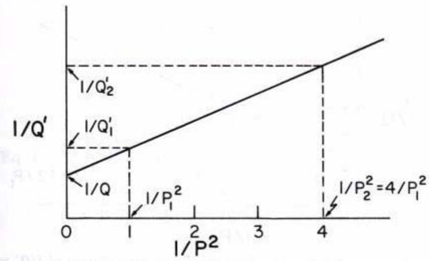


FIGURE 12.23. Graph of Eq. (12.28), illustrating the extrapolation of $1/Q'$ vs. $1/P^2$ to $1/P^2 = 0$, yielding $1/Q$. Thus the charge Q produced can be determined for the case of continuous radiation with general recombination occurring in an electronegative gas.

$$Q = \frac{3Q_1'Q_2'}{4Q_2' - Q_1'} \quad \text{and} \quad A_{ion} \equiv \frac{Q_1'}{Q} = \frac{4}{3} - \frac{Q_1'}{3Q_2'} \qquad (\text{for } P_1 = 2P_2)$$

F. Extrapolation for Initial Recombination

$$\frac{1}{Q'} = \frac{1}{Q} + \frac{c'}{P}$$

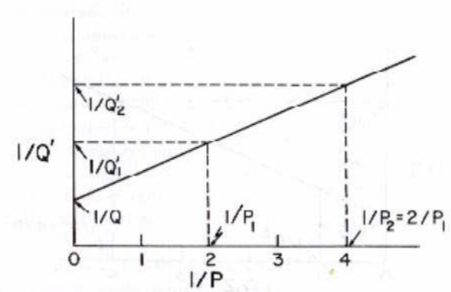


FIGURE 12.24. Graph of Eq. (12.34), illustrating the extrapolation of $1/Q'$ vs. $1/P$ to $1/P = 0$, yielding $1/Q$. Thus the charge Q can be determined for initial recombination with either pulsed or continuous radiation, or for general recombination with pulsed radiation only, in an electronegative gas.

G. Pulsed Radiation

$$Q \cong \frac{Q_1'Q_2'}{2Q_2' - Q_1'} \qquad (\text{for } P_1 = 2P_2, f > 0.96)$$

VI. IONIZATION, EXCITATION, AND W

A. Definition of W and $\overline{W}$

$$W = \frac{T_0(1 - g)}{\overline{N}(1 - g')}$$

$$\overline{W} = \frac{\sum_{i=1}^{n} T_i(1 - g_i)}{\sum_{i=1}^{n} N_i(1 - g_i')}$$

C. Experimental Measurement of W or $\overline{W}$

$$\frac{W}{e} = \frac{NT_0}{Q}$$

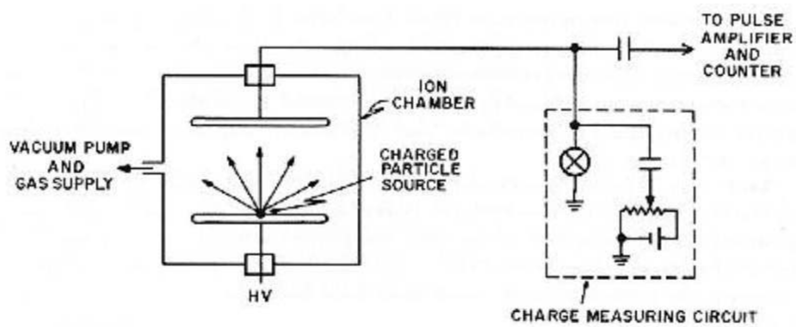


FIGURE 12.26. Schematic diagram of an experimental setup for measuring W/e.

F. *W* for Gas Mixtures

Approximately,

$$\left(\frac{1}{W}\right)_{mix} \cong \sum_i \left(\frac{P_i}{P} \cdot \frac{1}{W_i}\right)$$