FIGURE 20.3 (a) Distribution of ranges for charged particles. (b) Probability of a particle having a range larger than $R$.

where $\alpha$ is called the **straggling parameter**. Since $p(R) \, dR$ is the probability that the range will be within an interval $dR$ about $R$, the probability $P(R)$ that a particle will have a range larger than $R$ can be found by integrating the above distribution:

$$P(R) = \int_{R}^{\infty} p(R') \, dR'$$  \hspace{1cm} (17)

This is plotted as a function of $R$ in Figure 20.3b. As expected, $P(R)$ dips to $\frac{1}{2}$ at $R = R_0$. This curve, unlike the one for $p(R)$, is easy to obtain experimentally by noting the number of particles reaching a detector as the distance from a reference point is increased. In addition to $R_0$, the **extrapolated range** $R_{ex}$ is often measured from the $P(R)$ curve by finding the intersection with the abscissa of a line tangent to $P(R)$ at $R = R_0$, as is illustrated in Figure 20.3b. The quantity $R_{ex} - R_0$ is directly related to the straggling parameter:

$$R_{ex} - R_0 = \frac{P(R_0)}{-dP/dR} = \frac{\sqrt{\pi}}{2\alpha} \hspace{1cm} (m)$$  \hspace{1cm} (18)

where the derivative $dP/dR$ is evaluated at $R = R_0$. For $\alpha$ particles in air, for example, this amounts to about 1 percent of $R_0$.

**EXERCISE 2**

Verify the relationship between $R_{ex}$, $R_0$, and $\alpha$ given above by equation 18.

If the particle source has nonnegligible thickness, particles emitted from different locations within the source will have different ranges; the $P(R)$ curve in Figure 20.3b will thus be modified accordingly. The true mean range $R_0$ for particles emitted from such a source is no longer the same as $R_{1/2}$, which is the measured half-intensity distance. $R_0$ may still be calculated from a measurement of $R_{ex}$ and $R_{1/2}$; the technique is described concisely in reference 2, page 282.

**EXERCISE 3**

Indicate qualitatively, by means of a rough sketch, how Figure 20.3b would be modified for a source of nonnegligible thickness.

Measurements of the range and stopping power for charged particles emitted from radioactive sources may be accomplished either with a **surface barrier detector** in conjunction with a pulse analysis system or with an ionization chamber and an electrometer. In