The difference in energy, ΔE, between these two levels is proportional to the total magnetic field, B_{T}, at the nucleus:

$$\Delta E = kB_{\mathrm{T}},$$

where k is a proportionality constant that is different for different nuclides.

In a standard **nuclear magnetic resonance** (NMR) setup, the sample to be examined is placed in a static magnetic field. A radiofrequency (RF) pulse of electromagnetic radiation (that is, photons) is applied to the sample. If the frequency, f, of this pulse corresponds precisely to the energy difference between the two energy levels (Fig. 31–20), so that

$$hf = \Delta E = kB_{\mathrm{T}}, \qquad \textbf{(31–11)}$$

then the photons of the RF beam will be absorbed, exciting many of the nuclei from the lower state to the upper state. This is a resonance phenomenon, whose photons can be detected, since there is significant absorption only if f is very near $f = kB_{\mathrm{T}}/h$. Hence the name "nuclear magnetic resonance." For free ${}^1_1\mathrm{H}$ nuclei, the frequency is 42.58 MHz for a magnetic field $B_{\mathrm{T}} = 1.0\,\mathrm{T}$. If the H atoms are bound in a molecule the total magnetic field B_{T} at the H nuclei will be the sum of the external applied field (B_{ext}) plus the local magnetic field (B_{local}) due to electrons and nuclei of neighboring atoms. Since f is proportional to B_{T}, the value of f for a given external field will be slightly different for the bound H atoms than for free atoms:

$$hf = k(B_{\mathrm{ext}} + B_{\mathrm{local}}).$$

This small change in frequency can be measured, and is called the "chemical shift." A great deal has been learned about the structure of molecules and bonds using such NMR measurements.

PHYSICS APPLIED

NMR imaging (MRI)

For producing medically useful NMR images—now commonly called MRI, or **magnetic resonance imaging**—the element most used is hydrogen since it is the commonest element in the human body and gives the strongest NMR signals. The experimental apparatus is shown in Fig. 31–21. The large coils set up the static magnetic field, and the RF coils produce the RF pulse of electromagnetic waves (photons) that cause the nuclei to jump from the lower state to the upper one (Fig. 31–20). These same coils (or another coil) can detect the absorption of energy or the emitted radiation (also of frequency $f = \Delta E/h$, Eq. 31–11) when the nuclei jump back down to the lower state.

FIGURE 31–21 Typical NMR imaging setup: (a) diagram; (b) photograph.