single-junction cells. Consider an ideal single-junction cell with characteristic band gap E_g. A photon incident on this cell with photon energy $h\nu > E_g$ will be absorbed and converted to electrical energy, but the excess energy $h\nu - E_g$ will be lost as heat. The greater $h\nu$ is in excess of E_g, the lower is the fraction of that photon's energy that will be converted to electrical energy. On the other hand, a photon of energy $h\nu < E_g$ will not be absorbed and converted to electrical energy at all. Thus, the efficiency of photon conversion is a maximum efficiency at $h\nu = E_g$. Note that this maximum efficiency is less than 100%; the maximum work per absorbed photon is calculated by Henry [16].

Since the solar spectrum is broad, containing photons with energies in the range of about 0 to 4 eV, single-junction solar cell efficiencies are thus inherently limited to significantly less than the efficiency with which monochromatic light can be converted. The solution to this problem is (in principle) simple: rather than trying to convert all the photon energies with one cell with one band gap, divide the spectrum into several spectral regions and convert each with a cell whose band gap is tuned for that region. For instance, suppose the spectrum is divided into three regions $h\nu_1 - h\nu_2$, $h\nu_2 - h\nu_3$, and $h\nu_3 - \infty$, where $h\nu_1 < h\nu_2 < h\nu_3$. The light from these spectral regions would be converted by cells with band gaps $E_{g1} = h\nu_1$, $E_{g2} = h\nu_2$, and $E_{g3} = h\nu_3$, respectively. The greater the number of spectral regions allowed, the higher the potential overall efficiency.

9.3.2 Theoretical Limits to Multijunction Efficiencies

Henry has calculated the limiting terrestrial one-sun efficiencies for conversion with 1, 2, 3, and 36 band gaps; the respective efficiencies are 37, 50, 56, and 72% [16]. The improvement in efficiency on going from one to two band gaps is considerable, but the returns diminish as more band gaps are added. This is fortunate since the practicality of a device with more than four or five junctions is doubtful. Note that the promise of the multijunction efficiency improvements will not be realized unless the band gaps of the multiple junctions are correctly chosen; this choice will be discussed below in detail. Theoretical efficiency limits for multijunction devices based on thermodynamic fundamentals are presented in Chapter 4.

9.3.3 Spectrum Splitting

The multijunction approach requires that incident photons be directed onto the junction that is tuned to the photon's energy. Perhaps the conceptually simplest approach would be to use an optically dispersive element such as a prism to spatially distribute photons with different energies to different locations, where the appropriate cells would be placed to collect these photons. This approach is illustrated in Figure 9.4(a). Although conceptually simple, in practice the mechanical and optical complexities of this scheme make it undesirable in most circumstances. A generally preferable approach is to arrange the cells in a stacked configuration, as illustrated in Figure 9.4(b), arranged so that the sunlight strikes the highest band gap first, and then goes to the progressively lower band gap junctions. This arrangement makes use of the fact that junctions act as low-pass photon energy filters, transmitting only the sub–band gap light. Thus, in Figure 9.4(b), photons with $h\nu > E_{g3}$ get absorbed by that junction, photons with $E_{g2} < h\nu < E_{g3}$ get absorbed by the E_{g2} junction, and so on; in other words, the junctions themselves act as optical elements to