Answer to Essential Question 28.5: The common name for the element with the chemical symbol Po is polonium (not potassium, which has a chemical symbol of K). To write out the complete ground-state configuration of polonium, we can wind our way through Figure 28.9, starting from the top: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^6 6s^2 4f^{14} 5d^{10} 6p^4$.

28-6 Some Applications of Quantum Mechanics

Lasers

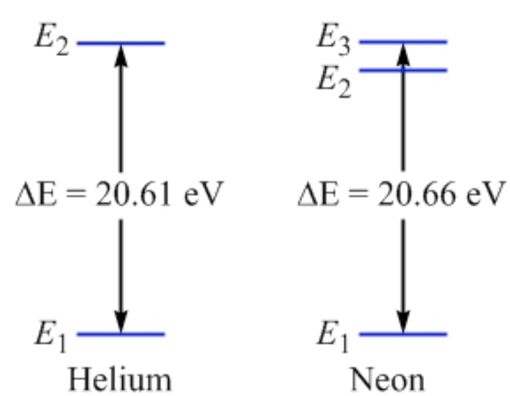
The word **laser** is an acronym, coming from the phrase light amplification by the stimulated emission of radiation. In our modern world, there are many applications of lasers. Such applications include bar-code readers in stores; surgery, particularly in eye surgery (including LASIK, Laser-Assisted in Situ Keratomileusis), where it is absolutely critical to do precision cutting; laser pointers, laser printers, and CD and DVD players; and fiber-optic communications.

The vast majority of lasers manufactured worldwide are diode lasers, in which light is produced from carefully constructed layers of semiconductors. In this section, we will focus on a different kind of laser, the helium-neon (or HeNe) laser that you may have seen in class or even used in a physics lab experiment. It is quite common to do demonstrations or experiments showing diffraction or interference of light using HeNe lasers.

As the name suggests, a helium-neon laser contains a mixture of helium and neon gas, at a relatively low pressure, with many more helium atoms than neon atoms. Coincidentally, the difference in energy between two of the electron energy levels in helium is almost the same as the difference in energy between two of the electron energy levels in neon – this is why these two elements are used. A high-voltage electrical discharge through the gas will excite helium atoms from their ground state to one of the $n = 2$ states, requiring an energy difference of 20.61 eV. These $n = 2$ states are **metastable**, which means that the electron will not immediately drop down to the ground state – it will remain in the excited state for a while.

With an extra 0.05 eV worth of kinetic energy, the excited helium atoms, when they collide with neon atoms that are in the ground state, can transfer 20.66 eV of energy to the neon atoms, just what is required to boost an electron in neon from the ground state to one of the $n = 3$ states (specifically, the 3s state). This level is also metastable, but electrons in some of these excited states will spontaneously drop down to the 2p state, emitting a photon of 632.8 nm (in air), corresponding to the wavelength of light emitted by a typical red HeNe laser. These photons interact with the excited neon atoms, which encourages them also to make the 3s to 2p transition. This part of the process is the *stimulated emission* that is part of what laser stands for. An energy-level diagram for the HeNe laser is shown in Figure 28.11.

Figure 28.11: An energy-level diagram for the HeNe laser. Because the energy difference between the two lowest energy levels in helium almost exactly equals the energy difference between the $n = 1$ and $n = 3$ levels in neon, excited helium atoms can transfer energy to ground-state neon atoms via collisions. Note that, despite what it looks like in the diagram, the E_1 levels in helium and neon are at completely different energies. What is critical, however, is that the difference between two of the helium levels almost exactly matches the difference between two of the neon levels.



Once the light has been created, by the process of stimulated emission inside the laser, a laser beam must then be created. The photons and the low-pressure mixture of helium and neon are contained in a tube that is typically 15 – 50 cm in length. At one end of the tube is a highly reflective mirror, while at the other end of the tube (the end that the beam emerges from) is a mirror that reflects most of the light, but which allows a little light (about 1%) to pass through. Generally, the photons emerge after bouncing back and forth many times between the mirrors, resulting in a beam of light that has very little spread.

The design of the mirrors inside the laser is also interesting, because the mirrors exploit thin-film interference for a wavelength corresponding to the wavelength of light emitted by the laser. There are several different electron transitions associated with helium and neon, so a HeNe laser can actually emit several different wavelengths (a different wavelength for each transition between electron energy levels). By adjusting the thin films on the mirrors inside the laser, the laser can be optimized for the emission of the standard 632.8 nm red light, or a different wavelength. The first HeNe laser ever made, in the 1960's, for instance, emitted ultraviolet light with a wavelength of 1150 nm.

Fluorescence and phosphorescence

Two more applications of quantum mechanics, again associated with electron energy levels and the photons that are emitted when electrons make a transition from a higher-energy state to a lower-energy state, are fluorescence and phosphorescence. These two phenomena are similar, in that exposing a fluorescent or phosphorescent material to (usually) ultraviolet light will excite electrons from lower-energy states to higher-energy states. When the electrons drop back toward the lower-energy state, however, they do so by dropping down a smaller step in energy, to an intermediate level. If this smaller energy causes photons to be emitted in the visible spectrum, we can then see them. In fluorescent materials, the phenomenon is present only when the light source that excites the upward transitions is present. In phosphorescent materials, it takes a long time, on average, before the excited electrons make a transition to a lower level. Because the electron transitions occur over a long time period, visible light continues to be emitted long after the light source that excites the upward transitions is removed. A photograph of a variety of fluorescent minerals is shown in Figure 28.12.

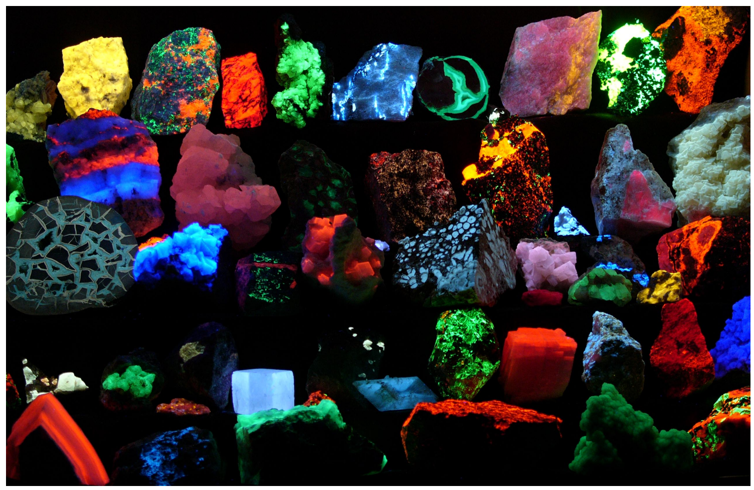


Figure 28.12: A variety of fluorescent minerals, photographed while they are being exposed to ultraviolet light. In general, these minerals are much less colorful when they are not fluorescing. Image credit: Hannes Grobe, via Wikimedia Commons.

Related End-of-Chapter Exercises: 12, 27.

Essential Question 28.6: Consider the information given in Figure 28.11. (a) If the $n = 3$ to $n = 2$ transition in neon produces a photon with a wavelength of 632.9 nm (in vacuum), what is the difference in energy between these two levels? (b) What is the difference in energy between the $n = 2$ and $n = 1$ levels in neon?