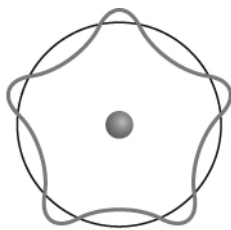


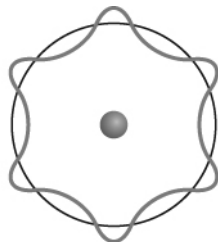
## Section 12.6: The Standard Model of Elementary Particles

### Tutorial 1 Practice, page 647

1. The orbits in Figure 5 have energy levels 4 and 7. So, energy levels 5 and 6 are allowed between these values.

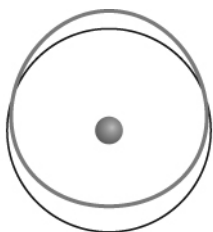


Allowed orbit for energy level 5

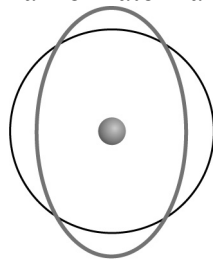


Allowed orbit for energy level 6

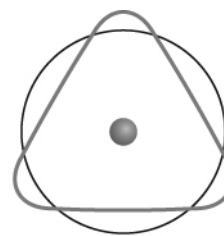
2. The first three energy levels of a Bohr atom are sketched below.



Energy level 1 of a Bohr atom



Energy level 2 of a Bohr atom



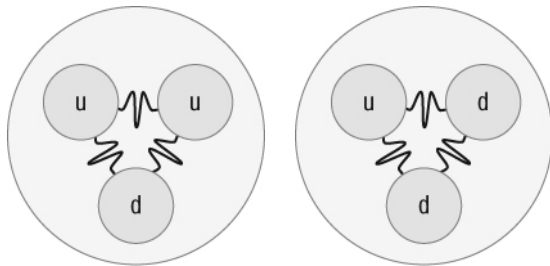
Energy level 3 of a Bohr atom

### Section 12.6 Questions, page 653

1. The Rutherford planetary model of the atom is inconsistent with classical physics because classical electrodynamics shows that an accelerating charged particle radiates energy. If an atom had orbiting electrons, as in the planetary model, then classically they would radiate and fall into the nucleus. Such a collapse would occur quickly. As we know that atoms are stable (otherwise, how could we exist?), the planetary model is inconsistent with classical physics.

2. The progression of atomic models involved the Rutherford model, the Bohr model, the later quantum model (Schrödinger and others), and the standard model. Rutherford's model was classical and did not work well, as explained in Question 1 above. The Bohr model, proposed by Niels Bohr and later strengthened by Louis de Broglie, was the first quantum model. It explained the hydrogen atom very well, but could not explain atoms with many electrons. Later quantum models, based on the Schrödinger equation, did well at explaining the behaviour of larger atoms and molecules, but did not explain the nucleus. The standard model is a complete model of the entire atom, describing not only the electrons, but also the nucleus.

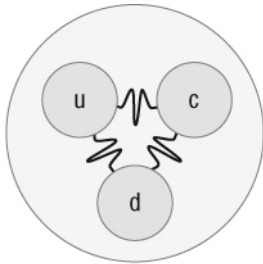
3. (a) Sketches of the constituent parts of the proton and neutron are below. The smaller circles with “u” and “d” are the quarks, and the wiggly lines connecting them represent the gluons, the force-mediating particles that hold the nucleus together.



parts of a proton

parts of a neutron

(b) Answers may vary. Sample answer: I decided to change one of the d quarks in the neutron to a c quark.



the charmed lambda particle

(c) In looking up the above particle in a list of baryons, I found it labelled the “charmed lambda.” Because the charm quark has the same charge as the up quark, the charmed lambda has a charge of +1. It is unstable, with a lifetime of about  $2.00 \times 10^{-13}$  s, and it is more than twice as heavy as the proton, at  $2286.46 \text{ MeV}/c^2$ .

4. Bosons have an important role in the standard model because they mediate the forces between particles. For example, the photon is the boson that mediates the electrodynamic force. In addition, the Higgs boson gives particles their mass.

5. (a) Fermions and bosons together are the building blocks of matter. The fermions include the leptons and quarks and can have charge. The bosons mediate the forces and provide mass.

(b) Mesons and baryons are hadrons, in that they are composed of quarks. Whereas the baryons have three quarks and include the particles of the nucleus, the proton and neutron, the mesons have just two quarks and are all unstable.

(c) Leptons and hadrons are both particles, but leptons do not contain quarks. Leptons are the family of particles that include the electron, its neutrino, and its antiparticle. Unlike the leptons, hadrons are composite particles, being made out of quarks and including mesons and baryons.

6. The standard model describes how matter is composed and how interactions occur through the electromagnetic force and both the weak and the strong nuclear force. The model describes matter as being made up of quarks and leptons, with their forces mediated by bosons. However, the standard model does not describe gravity.

**7.** The only significant missing piece in the standard model is the Higgs boson. The standard model says the Higgs exists, but it has never been detected. So, the discovery of the Higgs boson would help to verify the standard model and help us understand the origin of mass.

**8.** Scientist may think that there must be a theory of everything for a few reasons. One, there is the general idea that the universe can be understood. Without a theory of everything, we do not understand why the microscopic realm is described by one theory, the standard model, whereas the large-scale structure is described by another theory, general relativity. In addition, the trend in science is to unify. First Newton unified the mechanics on Earth with the motions of the planets. Later Maxwell unified electricity and magnetism. And more recently, the standard model unified electromagnetism with the nuclear forces. Next on the list is to unify all forces in one grand theory. With a grand theory of everything, scientists may better understand the origin of the universe as well as many other mysteries, and also discover new phenomena.

**9.** Newton unified physics in the sense that the same gravitational force that objects on Earth respond to also acts on celestial objects. Moreover, Newton proposed that all matter attracts other matter gravitationally; that is, gravity is a universal force between all masses.

**10.** Answer may vary. Various pieces of the standard model have come from many scientists. Students will research the history of the standard model and choose a scientist who made an important contribution to the standard model. Scientists fitting this description would have to include many Nobel Prize winners—Murray Gell-Mann, Jerome I. Friedman, Henry W. Kendall, Richard E. Taylor, Yoichiro Nambu, Makoto Kobayashi, Toshihide Maskawa, Emilio Gino Segrè, Owen Chamberlain, Sin-Itiro Tomonaga, Julian Schwinger, Richard P. Feynman, Sheldon Lee Glashow, Abdus Salam, Steven Weinberg, Gerardus 't Hooft, Martinus J.G. Veltman, David Politzer, David Gross, Frank Wilczek, Burton Richter, Samuel Ting, Martin Perl, Frederick Reines, Leon M. Lederman, Melvin Schwartz, Jack Steinberger, Chen Ning Yang, Tsung-Dao (T.D.) Lee, Carlo Rubbia, and Simon Van der Meer—and many others, including Gerson Goldhaber, Francois Pierre, James Bjorken, John Iliopoulos, Luciano Maiani, Donald Perkins, Charles Prescott, Harald Fritzsch, George Zweig, O.W. Greenberg, M.Y. Han, Harald Fritzsch, and Chien-Shiung Wu.