Chapter 40

All About Atoms

40.1: Some Properties of Atoms:

Atoms are stable. Essentially all the atoms that form our tangible world have existed without change for billions of years.

Atoms combine with each other. They stick together to form stable molecules and stack up to form rigid solids.

40.1: Some Properties of Atoms: Atoms Are Put Together Systematically

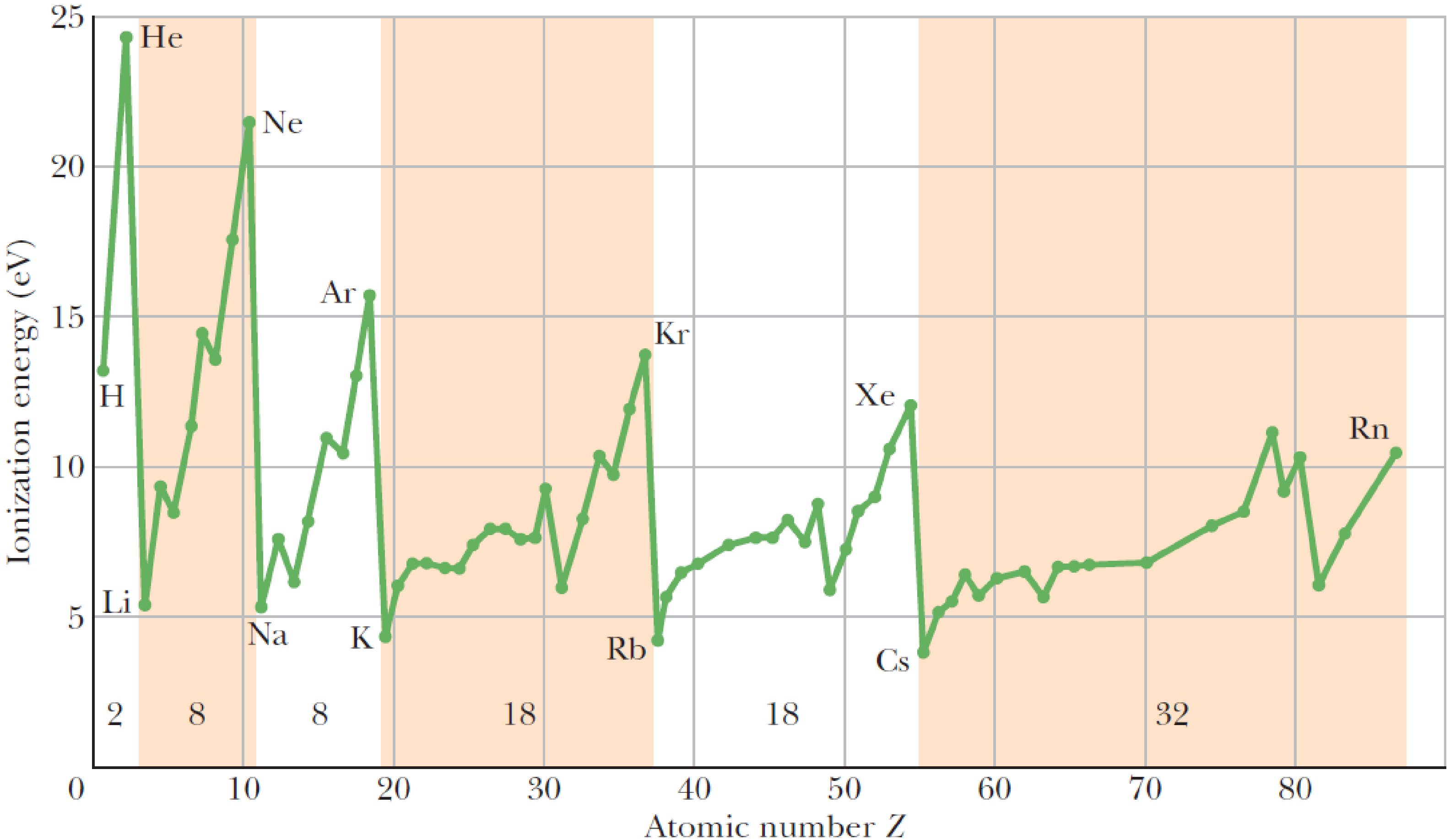


Fig. 40-2 A plot of the ionization energies of the elements as a function of atomic number, showing the periodic repetition of properties through the six complete horizontal periods of the periodic table. The number of elements in each of these periods is indicated.

40.1: Some Properties of Atoms: Atoms Are Put Together Systematically

The elements are arranged in the periodic table in six complete horizontal ***periods*** (and a seventh incomplete period): except for the first, each period starts at the left with a highly reactive alkali metal (lithium, sodium, potassium, and so on) and ends at the right with a chemically inert noble gas (neon, argon, krypton, and so on).

Quantum physics accounts for the chemical properties of these elements.

The numbers of elements in the six periods are 2, 8, 8, 18, 18, and 32.

Quantum physics predicts these numbers.

40.1: Some Properties of Atoms: Atoms Emit and Absorb Light:

An atom can make a transition from one state to another by emitting light (to jump to a lower energy level E_{low}) or by absorbing light (to jump to a higher energy level E_{high}).

The light is emitted or absorbed as a photon with energy

$$hf = E_{\text{high}} - E_{\text{low}}.$$

40.1: Some Properties of Atoms: Atoms have Angular Momentum and Magnetism

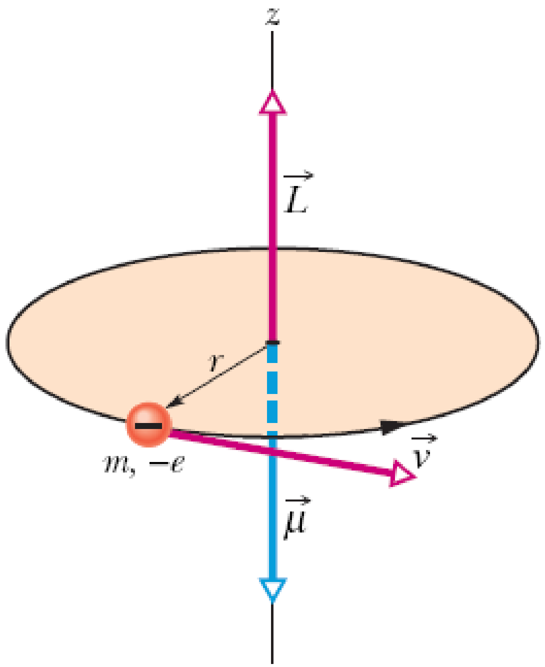
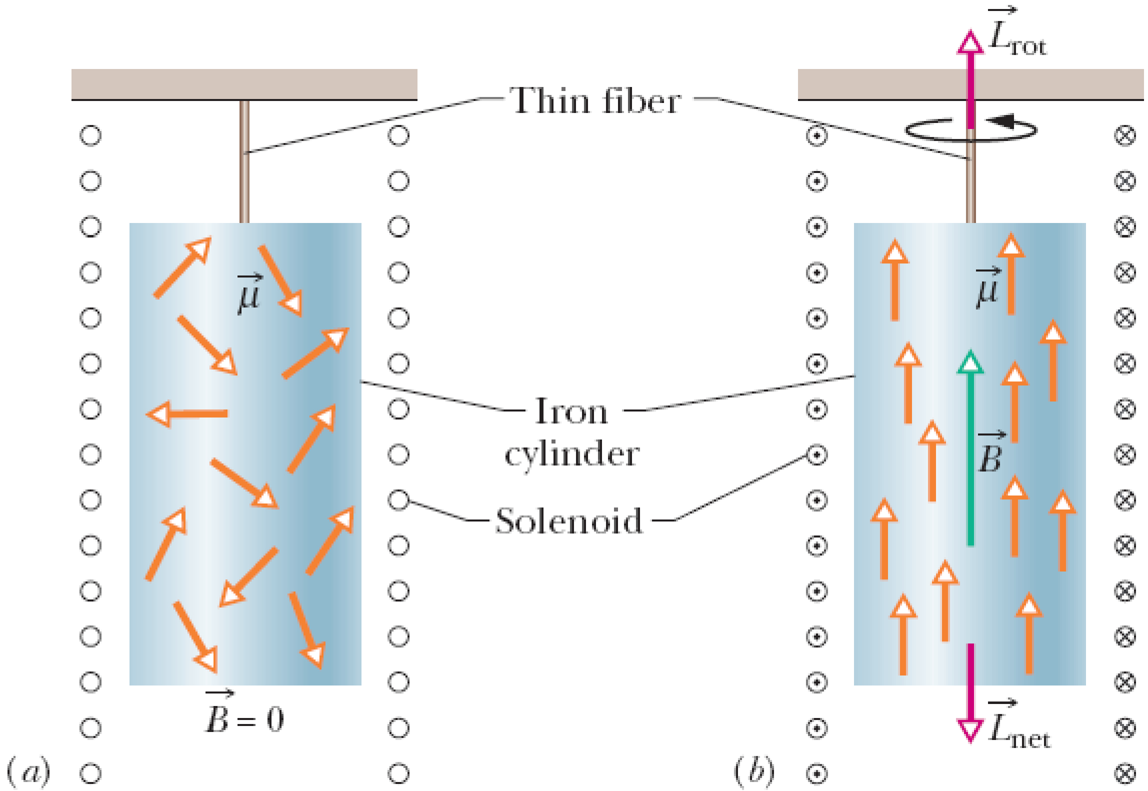


Fig. 40-3 A classical model showing a particle of mass m and charge $-e$ moving with speed v in a circle of radius r. The moving particle has an angular momentum $\vec{L}$ given by $\vec{r} \times \vec{p}$, where $\vec{p}$ is its linear momentum $m\vec{v}$. The particle's motion is equivalent to a current loop that has an associated magnetic moment $\vec{\mu}$ that is directed opposite $\vec{L}$.

40.2: Some Properties of Atoms: The Einstein-de Hass Experiment



Aligning the magnetic moment vectors rotates the cylinder.

Fig. 40-4 The Einstein–de Haas experimental setup. (a) Initially, the magnetic field in the iron cylinder is zero and the magnetic dipole moment vectors of its atoms are randomly oriented. (b)When a magnetic field is set up along the cylinder's axis, the magnetic dipole moment vectors $\boldsymbol{\mu}$ line up parallel to and the cylinder begins to rotate.

Electron Spin:

The electron has an intrinsic ***spin angular momentum*** $\vec{S}$, often called simply ***spin.***

The magnitude of $\vec{S}$ is quantized and depends on a ***spin quantum number*** s, which is always ½ for electrons (and for protons and neutrons).

The component of $\vec{S}$ is measured along any axis, is quantized, and depends on a ***spin magnetic quantum number*** m_s, which can have only the value +½ or -½

Table 40-1

Electron States for an Atom

Quantum Number	Symbol	Allowed Values	Related to
Principal	n	$1, 2, 3, \ldots$	Distance from the nucleus
Orbital	ℓ	$0, 1, 2, \ldots, (n-1)$	Orbital angular momentum
Orbital magnetic	m_ℓ	$0, \pm 1, \pm 2, \ldots, \pm \ell$	Orbital angular momentum (z component)
Spin	s	$\frac{1}{2}$	Spin angular momentum
Spin magnetic	m_s	$\pm\frac{1}{2}$	Spin angular momentum (z component)

Angular Momenta and Magnetic Dipole Moments:

The magnitude *L of the* ***orbital angular momentum L*** of an electron in an atom is quantized; that is, it can have only certain values

$$L = \sqrt{\ell(\ell + 1)}\hbar,$$

The magnetic dipole has an ***orbital magnetic dipole moment*** $\boldsymbol{\mu_{orb}}$, is related to the angular momentum by

$$\vec{\mu}_{\rm orb} = -\frac{e}{2m}\vec{L}. \quad = \frac{e}{2m}\sqrt{\ell(\ell + 1)}\hbar.$$

If the atom is located in a magnetic field ***B***, with a *z* axis extending in the direction of the field lines at the atom's location, we can measure the *z* components of $\boldsymbol{\mu_{orb}}$ and ***L*** along that axis.

$$\mu_{{\rm orb},z} = -m_\ell \mu_{\rm B}.$$

Here μ_B is the ***Bohr Magneton***

$$\mu_{\rm B} = \frac{eh}{4\pi m} = \frac{e\hbar}{2m} = 9.274 \times 10^{-24}\ {\rm J/T}$$

Angular Momenta and Magnetic Dipole Moments:

The components L_z of the angular momentum are also quantized, and they are given by

$$L_z = m_\ell \hbar.$$

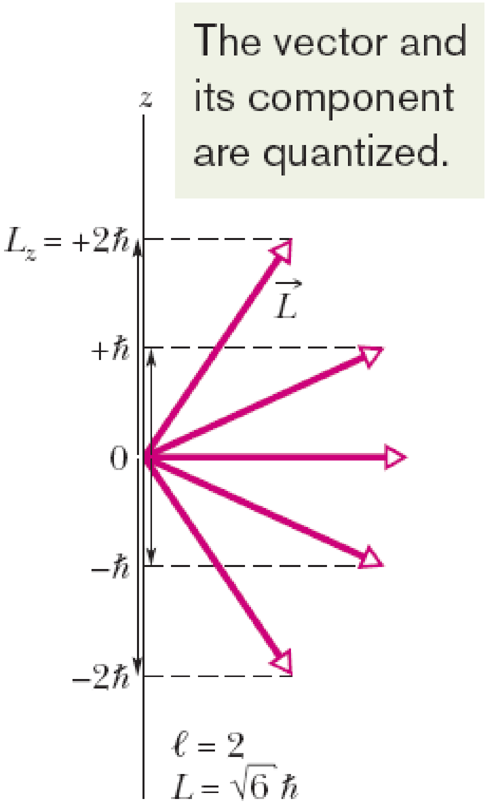


Fig. 40-5 The allowed values of L_z for an electron in a quantum state with $\ell = 2$. For every orbital angular momentum vector $\vec{L}$ in the figure, there is a vector pointing in the opposite direction, representing the magnitude and direction of the orbital magnetic dipole moment $\vec{\mu}_{orb}$.

Angular Momenta and Magnetic Dipole Moments:

$$S = \sqrt{s(s+1)}\hbar = \sqrt{(\tfrac{1}{2})(\tfrac{1}{2}+1)}\hbar = 0.866\hbar,$$

$$\vec{\mu}_s = -\frac{e}{m}\vec{S}. \qquad \text{(Spin magnetic dipole moment)}$$

$$= \frac{e}{m}\sqrt{s(s+1)}\hbar.$$

$S_z = m_s\hbar,$ (components of ***S*** can be measured along a preferred axis).

$m_s = +\frac{1}{2}$

$m_s = -\frac{1}{2}$

(Spin angular quantum number can only have two values)

$\mu_{s,z} = -2m_s\mu_B.$ (The components of $\mu_{s,z}$ are also quantized)

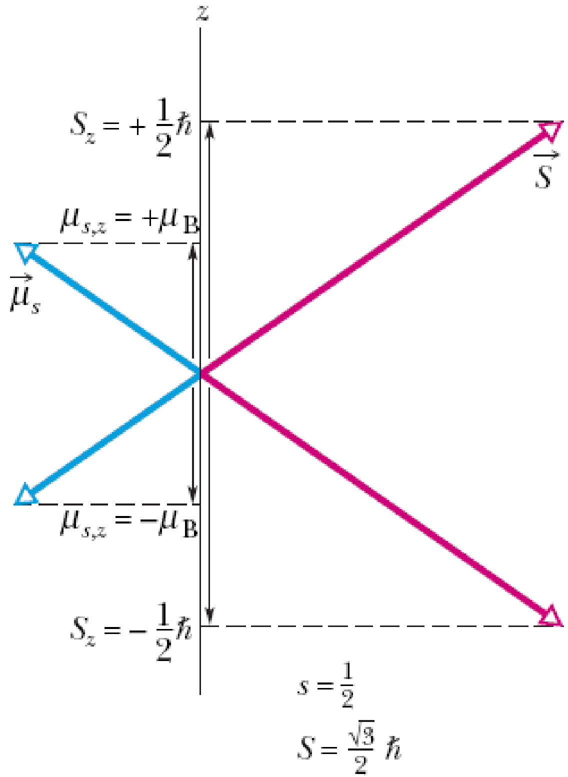


Fig. 40-6 The allowed values of S_z and μ_z for an electron.

Angular Momenta and Magnetic Dipole Moments:

For an atom containing more than one electron, we define a total angular momentum, $\vec{J}$, which is the vector sum of orbital and their spin angular momenta of the individual electrons.

This number of protons is defined as being the ***atomic number*** Z of the element.

$$\vec{J} = (\vec{L}_1 + \vec{L}_2 + \vec{L}_3 + \cdots + \vec{L}_Z) + (\vec{S}_1 + \vec{S}_2 + \vec{S}_3 + \cdots + \vec{S}_Z).$$

The ***effective magnetic dipole moment, μ_{eff},*** for the atom is the component of the vector sum of the individual magnetic dipole moments in the direction of $-\vec{J}$.

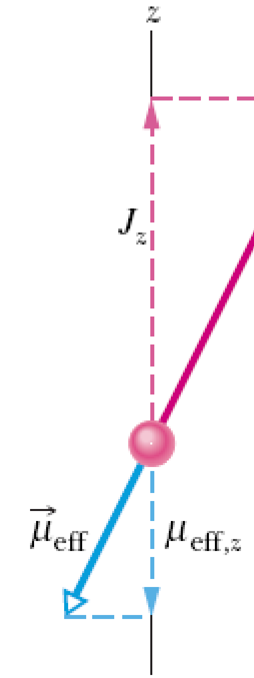


Fig. 40-7 A classical model showing the total angular momentum vector $\vec{J}$ and the effective magnetic moment vector $\vec{\mu}_{\text{eff}}$.

Checkpoint 1

An electron is in a quantum state for which the magnitude of the electron's orbital angular momentum $\vec{L}$ is $2\sqrt{3}\hbar$. How many projections of the electron's orbital magnetic dipole moment on a z axis are allowed?