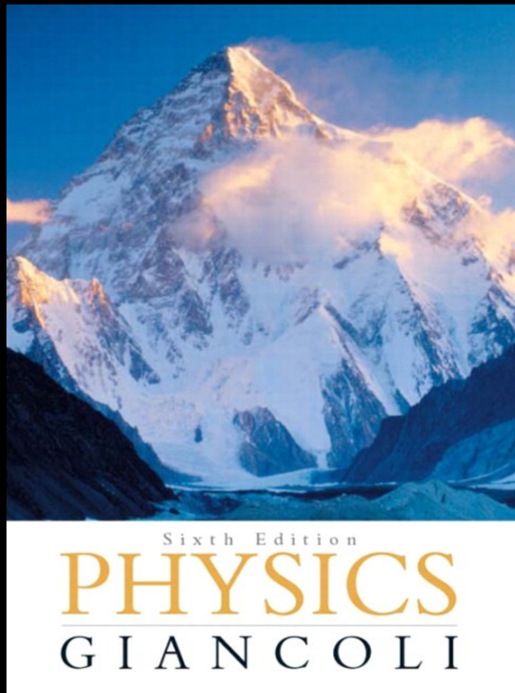


Lecture PowerPoint

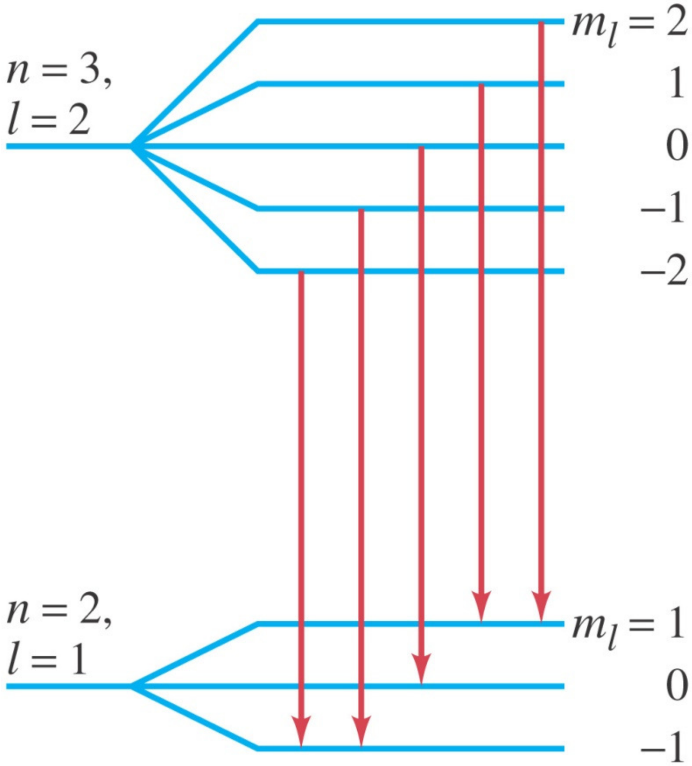
Chapter 28

Physics: Principles with Applications, 6th edition

Giancoli

Chapter 28

Quantum Mechanics of Atoms



Units of Chapter 28

- The Wave Function and Its Interpretation; the Double-Slit Experiment
- The Heisenberg Uncertainty Principle
- Quantum Numbers
- Complex Atoms; the Exclusion Principle
- The Periodic Table of Elements
- Lasers

28.1 Quantum Mechanics – “The” Theory

Quantum mechanics incorporates wave-particle duality, and successfully explains energy states in complex atoms and molecules, the relative brightness of spectral lines, and many other phenomena.

It is widely accepted as being the fundamental theory underlying all physical processes.

On the flip side, quantum mechanics is famously strange and weird when its ideas are translated to the everyday world.

The Correspondence principle can resolve most of these paradoxes

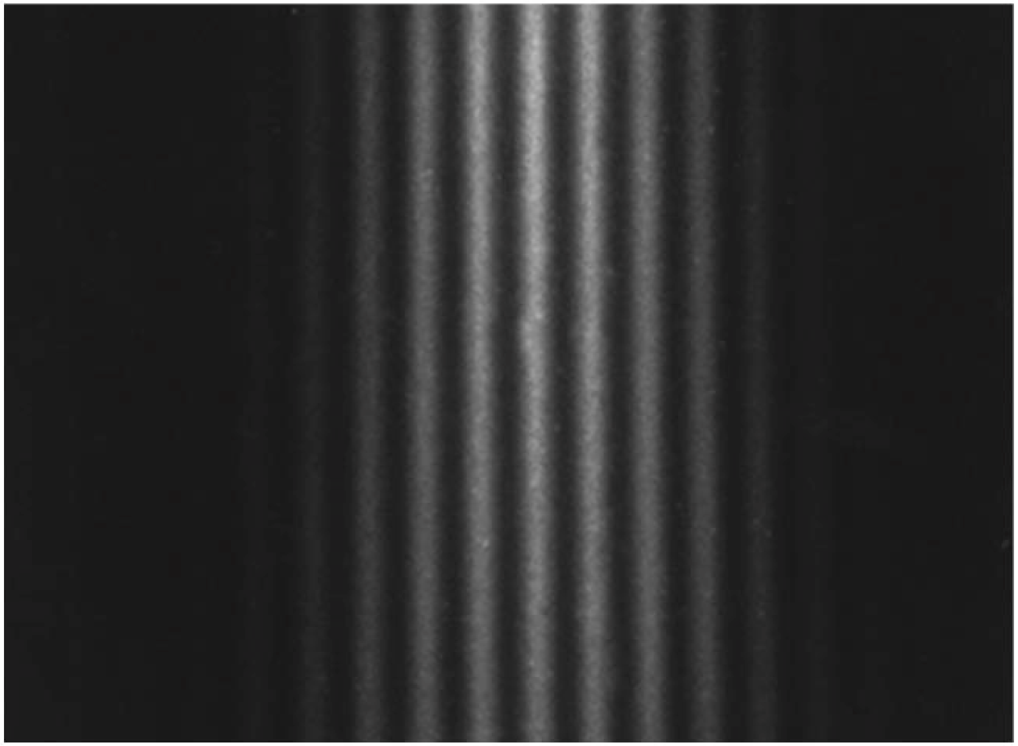
28.2 The Wave Function and Its Interpretation; the Double-Slit Experiment

• de Broglie's matter-wave idea predicts that particles like electrons should exhibit interference just as light does.

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

De Broglie wavelength for a moving particle

• An electron beam passing through a double slit indded produces an interference pattern similar to that for light.

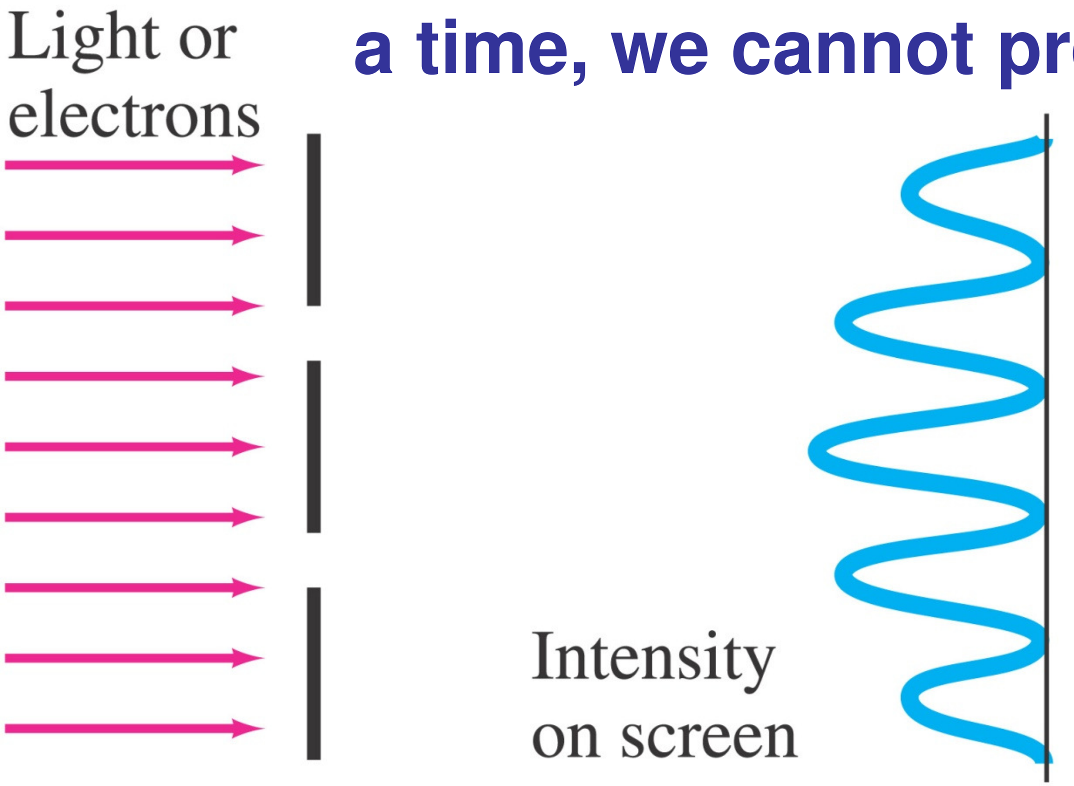


• Interference happens even if the electrons (or photons) are sent through one at a time!

28.2 The Wave Function and Its Interpretation; the Double-Slit Experiment

The interference pattern is observed after many electrons have gone through the slits.

If we send the electrons through one at a time, we cannot predict the path any single electron will take, but we can predict the overall distribution.



28.3 The Heisenberg Uncertainty Principle

Quantum mechanics tells us there are limits to measurement – not because of the limits of our instruments, but inherently.

This is due to the wave-particle duality, and to interaction between the observing equipment and the object being observed.

28.3 The Heisenberg Uncertainty Principle

Werner Heisenberg showed that the more you pin down one quantity, the more the other is affected.

The product of these uncertainties has a finite value: Plank's constant.

$$(\Delta x)(\Delta p_x) \approx h$$

This is called the Heisenberg uncertainty principle.

It tells us that the position and momentum of a particle cannot simultaneously be measured with precision.

28.3 The Heisenberg Uncertainty Principle

It can also be written as a relation between the uncertainty in time and the uncertainty in energy:

$$(\Delta E)(\Delta t) \approx h$$

This says that if an energy state only lasts for a limited time, its energy will be uncertain.

In a high pressure gas, frequent collisions stimulate atoms in excited states to de-excite and emit photons almost immediately. This shortening of the lifetime produces an small variation in the emitted photon's energy.

As a consequence, the width of spectral lines can directly reveal gas pressure, for example in stars and gas clouds in outer space!

This effect is called Pressure Broadening

Think about how this situation is analagous to the uncertainty principle….

A motion blurred photo can be used to measure the speed of an object, but not its accurate position.

A faster shutter speed would freeze the motion giving an accurate position, but it would not reveal the speed

28.6 Quantum Mechanics of the Hydrogen Atom; Quantum Numbers

There are four different quantum numbers needed to specify the state of an electron in an atom.

Principal quantum number n gives the total energy associated with a state or energy level.

$$E_n = -\frac{13.6\text{ eV}}{n^2}, \qquad n = 1, 2, 3, \cdots$$

28.6 Quantum Mechanics of the Hydrogen Atom; Quantum Numbers

This table summarizes the four quantum numbers.

TABLE 28–1 Quantum Numbers for an Electron

Name	Symbol	Possible Values
Principal	n	$1, 2, 3, \cdots, \infty$.
Orbital	l	For a given n: l can be $0, 1, 2, \cdots, n-1$.
Magnetic	m_l	For given n and l: m_l can be $l, l-1, \cdots, 0, \cdots, -l$.
Spin	m_s	For each set of n, l, and m_l: m_s can be $+\frac{1}{2}$ or $-\frac{1}{2}$.

28.7 Complex Atoms; the Exclusion Principle

In order to understand the electron distributions in atoms, another principle is needed. This is the Pauli exclusion principle:

No two electrons in an atom can occupy the same quantum state.

The quantum state is specified by the four quantum numbers; no two electrons can have the same set.

This led to the formation of Periodic table.

28.8 The Periodic Table of the Elements

TABLE 28–2 Value of *l*

Value of l	Letter Symbol	Maximum Number of Electrons in Subshell
0	s	2
1	p	6
2	d	10
3	f	14
4	g	18
5	h	22
⋮	⋮	⋮

We can now understand the organization of the periodic table.

Electrons with the same n are in the same shell. Electrons with the same n and l are in the same subshell.

The exclusion principle limits the maximum number of electrons in each subshell to $2(2l + 1)$.

Each value of l is given its own letter symbol.

28.8 The Periodic Table of the Elements

Electron configurations are written by giving the value for n, the letter code for l, and the number of electrons in the subshell as a superscript.

For example, here is the ground-state configuration of sodium (Z = 11):

$$1s^2 2s^2 2p^6 3s^1$$

28.8 The Periodic Table of the Elements

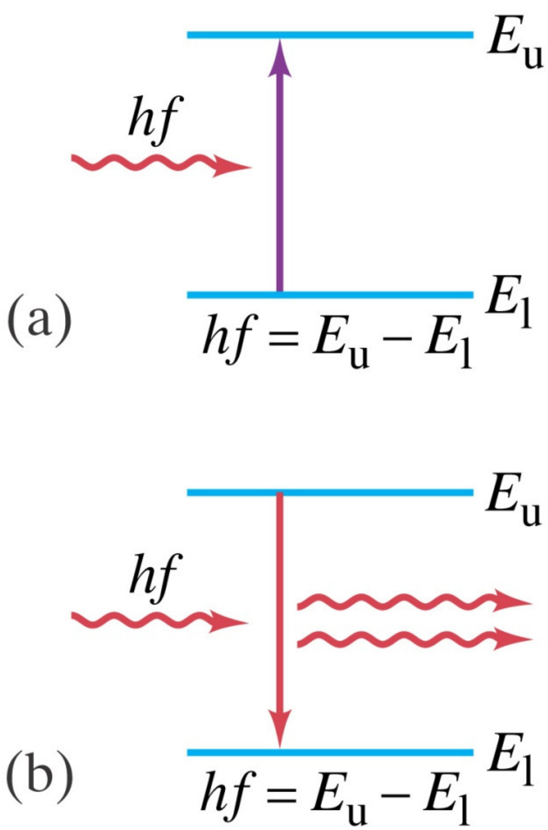
This table shows the configuration of the outer electrons only.

TABLE 28–3
Electron Configuration of Some Elements

Z (Number of Electrons)	Element†	Ground State Configuration (outer electrons)
1	H	$1s^1$
2	He	$1s^2$
3	Li	$2s^1$
4	Be	$2s^2$
5	B	$2s^2 2p^1$
6	C	$2s^2 2p^2$
7	N	$2s^2 2p^3$
8	O	$2s^2 2p^4$
9	F	$2s^2 2p^5$
10	Ne	$2s^2 2p^6$
11	Na	$3s^1$
12	Mg	$3s^2$
13	Al	$3s^2 3p^1$
14	Si	$3s^2 3p^2$
15	P	$3s^2 3p^3$
16	S	$3s^2 3p^4$
17	Cl	$3s^2 3p^5$
18	Ar	$3s^2 3p^6$
19	K	$4s^1$
20	Ca	$4s^2$
21	Sc	$3d^1 4s^2$
22	Ti	$3d^2 4s^2$
23	V	$3d^3 4s^2$
24	Cr	$3d^5 4s^1$
25	Mn	$3d^5 4s^2$
26	Fe	$3d^6 4s^2$

28.11 Lasers

A laser produces a narrow, intense beam of coherent light. This coherence means that, at a given cross section, all parts of the beam have the same phase.



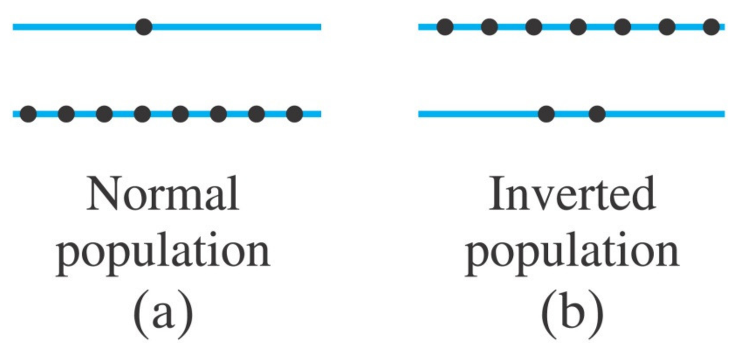
(a) Absorption of a photon.

(b) Stimulated emission – if the atom is already in the excited state, the presence of another photon of the same frequency can stimulate the atom to make the transition to the lower state sooner. These photons are in phase.

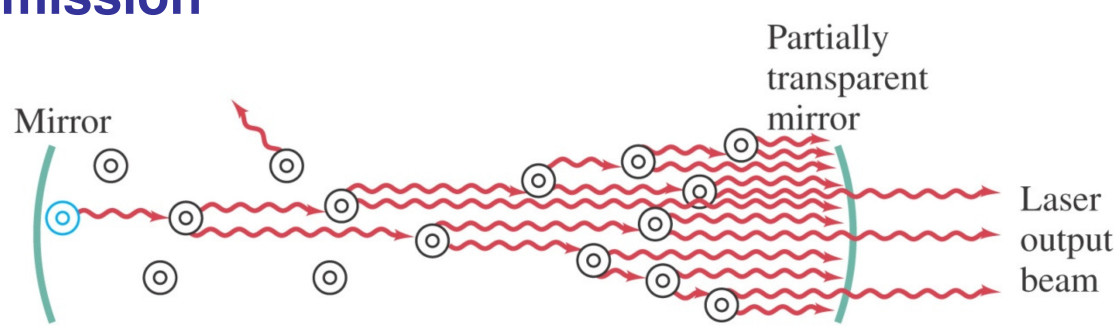
28.11 Lasers

To obtain coherent light from stimulated emission, two conditions must be met:

1. Most of the atoms must be in the excited state; this is called an inverted population.

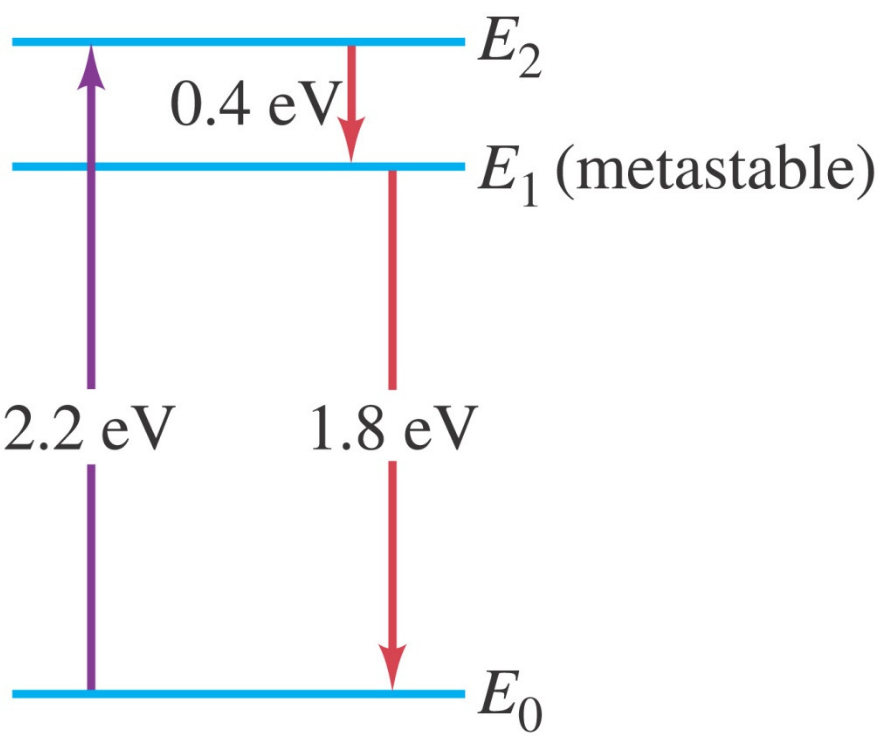


2. The higher state must be a metastable state, so that once the population is inverted, it stays that way. This means that transitions occur through stimulated emission rather than spontaneously.



28.11 Lasers

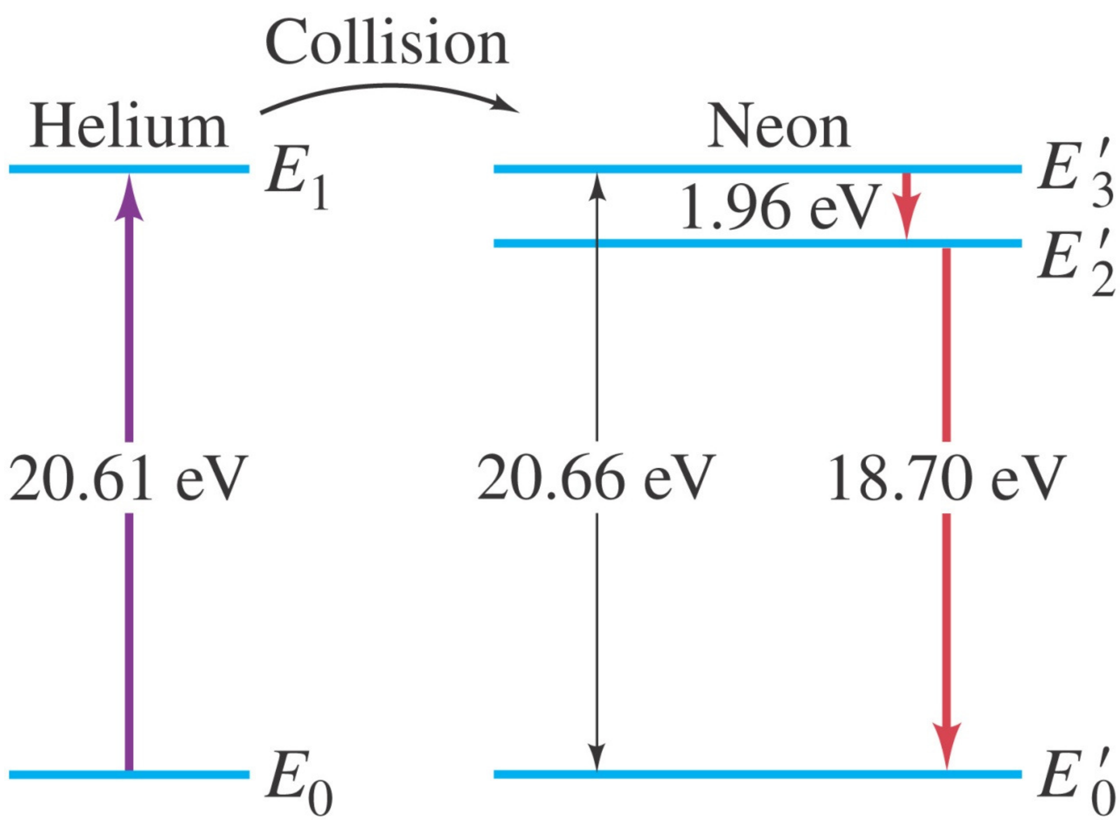
The laser beam is narrow, only spreading due to diffraction, which is determined by the size of the end mirror.



An inverted population can be created by exciting electrons to a state from which they decay to a metastable state. This is called optical pumping.

28.11 Lasers

A metastable state can also be created through interactions between two sets of atoms, such as in a helium-neon laser.



Summary of Chapter 28

- Quantum mechanics is the basic theory at the atomic level; it is statistical rather than deterministic
- Heisenberg uncertainty principle: $(\Delta p_x)(\Delta x) \gtrsim \hbar$

$$(\Delta E)(\Delta t) \gtrsim \hbar$$

- Electron state in atom is specified by four numbers:

  n, l, m_l, and m_s

- Pauli exclusion principle: no two electrons in the same atom can be in the same quantum state
- Electrons are grouped into shells and subshells
- Periodic table reflects shell structure