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NEW JERSEY CENTER
FOR TEACHING & LEARNING

Chemistry

Atomic Structure

2015-08-29

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The Bohr Model

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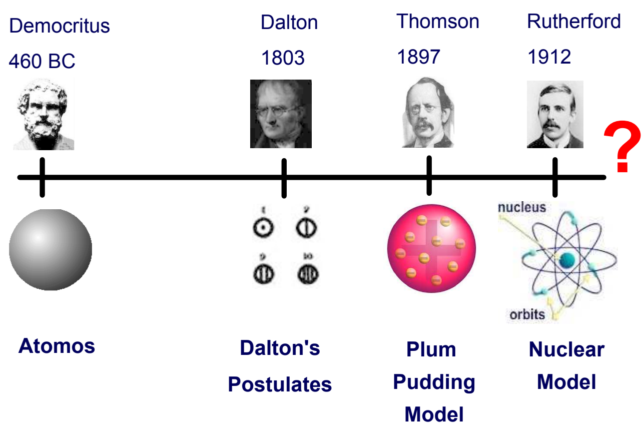
Evolution of Atomic Theory



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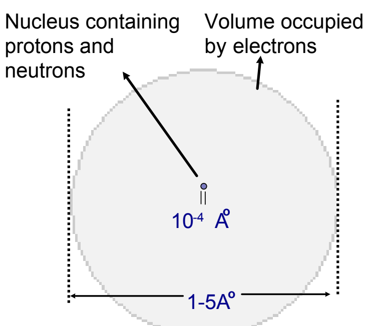
The Problem with the Nuclear Atom

So far we have established:

1. Atoms are composed of protons, neutrons, and electrons.

2. The protons and neutrons comprise the vast majority of the mass of an atom and are found together in the small, dense nucleus.

3. The electrons are found outside the nucleus and occupy the vast majority of the volume.



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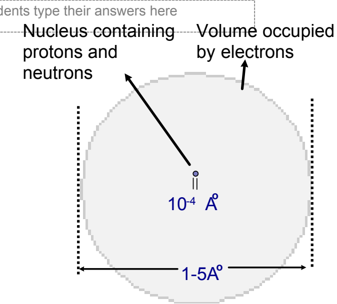
1 **The Problem with the Nuclear Atom**

Students type their answers here



Question: What are some physical problems with this model?

Slide 7 (Answer) / 155

1 **The Problem with the Nuclear Atom**

Students type their answers here

Answer

Positive and negative charges attract, so why aren't the electrons and protons together?

Why don't the electrons "fall" into the nucleus?

Question: What are some physical problems with this model?

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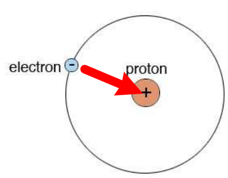
The Problem with the Nuclear Atom

The nucleus of an atom is small, 1/10,000 the size of the atom. The electrons are outside the nucleus, moving freely within the vast empty atom. The nucleus is positive; the electron is negative.

There is an electric force, $F_E = kq_1q_2/r^2$, pulling the electrons towards the nucleus.
There is no other force acting on the electrons; they feel a net force towards the nucleus.



Why don't the electrons fall in...
why doesn't the atom collapse into its nucleus?

The Problem with the Nuclear Model

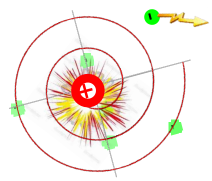
Perhaps electrons orbit the nucleus...like planets orbit the sun. If this were the case, electrons would constantly be accelerating as they travel in a circle:

$$a = v^2/r$$

However, an accelerating charge radiates electromagnetic energy...light.

As a charge radiates light it loses energy. All the kinetic energy would be radiated away in about a billionth of a second...then the electron would fall into the nucleus. All the atoms in the universe would collapse.

Death spiral of the electron.



https://phet.colorado.edu/sims/radiating-charge/radiating-charge_en.html

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The Problem with the Nuclear Model

Our observations tell us the nuclear model is insufficient

1. Most atoms are stable and do not release energy at all.

If electrons were continuously orbiting the nucleus in uniform circular motion, they would be accelerating, and accelerating charges release energy. This is not observed.

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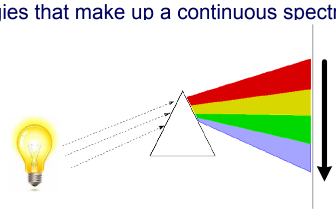
The Problem with the Nuclear Model

If the Rutherford model of the atom were correct, the atom should emit energy as the orbit of the electron decays.

Since the electron would speed up as it decays, the amount of energy released should be of an increasingly higher frequency.

When light, a form of energy, passes through a prism, it is shown to be made up light waves of many different frequencies and energies that make up a continuous spectrum.



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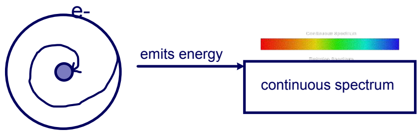
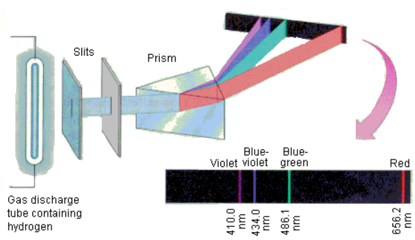
The Problem with the Nuclear Model

If electrons in atoms were constantly releasing energy at increasing frequencies, we would see this emission of energy at increasingly high frequency. This would create what is called a continuous spectrum representing all frequencies of light.



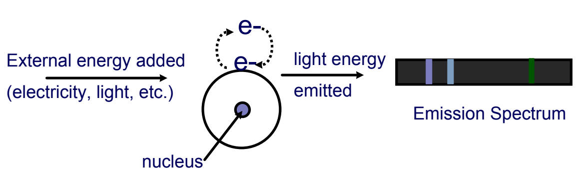
The Problem with the Nuclear Model

When electricity is passed through gases (made up of atoms), the atoms become energized but appear to emit energy in very unique patterns.



The Problem with the Nuclear Model

2. When energized atoms do emit energy, a continuous spectrum is not produced; instead, an emission spectrum is produced displaying emitted light at specific wavelengths and frequencies.



2 An accelerating charge emits light energy.

- True
- False

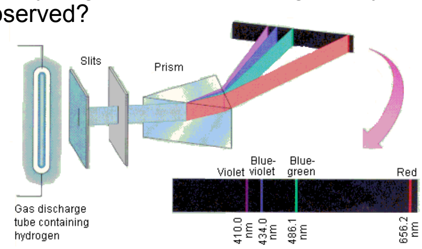
2 An accelerating charge emits light energy.

- True
- False

Answer

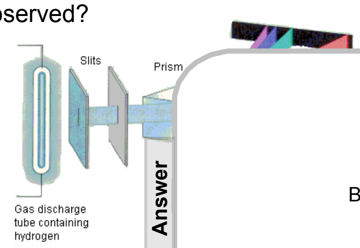
True

3 When hydrogen atoms are energized by electricity, what is observed?



- A continuous spectrum of light
- An emission spectrum of specific colors only.
- Neither a nor b

3 When hydrogen atoms are energized by electricity, what is observed?



Answer

B

- A continuous spe
- An emission spect
- Neither a nor b

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4 Why was the Nuclear Model insufficient?

- It could not explain the existence of emission spectra
- It could not account for the stability of the atom
- It required the electrons to be in the nucleus and the protons in orbit around the nucleus
- A and B

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4 Why was the Nuclear Model insufficient?

- It could not expla
spectra
- It could not acc
- It required the el
the protons in or
- A and B

Answer

D

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Emission Spectra and the Bohr Model

A scientist named Niels Bohr interpreted these observations and created a new model of the atom that explained the existence of emission spectra and provided a framework for where the electrons can exist around the nucleus.

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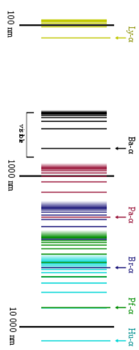
Emission Spectra and the Bohr Model

Bohr knew that the wavelengths seen in the emission spectra of hydrogen had a regular pattern. Each series was named after the scientist who observed these particular spectral lines.



Lyman Series
(spectral lines in the UV range)

$$\frac{1}{\lambda} = R\left(\frac{1}{1^2} - \frac{1}{n^2}\right), \qquad n = 2, 3, \cdots$$

Balmer Series
(spectral lines in the visible and UV range)

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right), \qquad n = 3, 4, \cdots$$

Paschen Series
(spectral lines in the infrared range)

$$\frac{1}{\lambda} = R\left(\frac{1}{3^2} - \frac{1}{n^2}\right), \qquad n = 4, 5, \cdots$$

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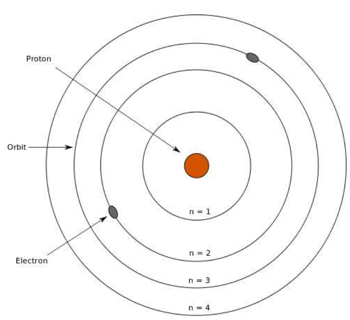
Emission Spectra and the Bohr Model

Each of these patterns include the variable "n" but no one knew what "n" was. Bohr proposed that "n" referred to a particular orbit around the nucleus where an electron could be.

Bohr proposed that electrons could orbit the nucleus, like planets orbit the sun...but only in certain specific orbits.

He then said that in these orbits, they wouldn't radiate energy, as would be expected normally of an accelerating charge. These stable orbits would somehow violate that rule.



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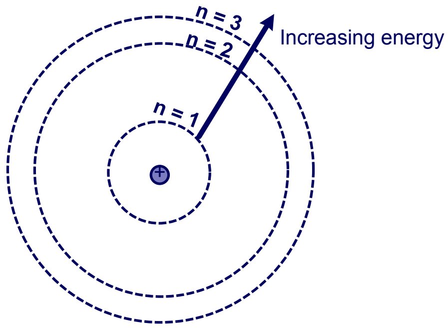
Emission Spectra and the Bohr Model

Each orbit would correspond to a different energy level for the electron.



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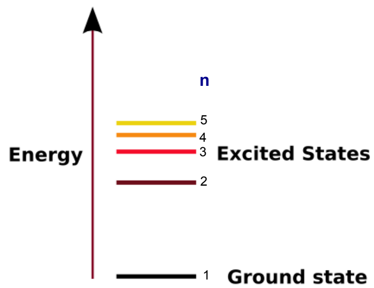
The Bohr Atom

The lowest energy level is called the ground state; the others are excited states.



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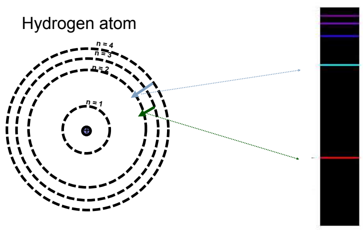
Emission Spectra and the Bohr Model

Bohr reasoned that each spectral line was being produced by an electron "decaying" from a high energy Bohr orbit to a lower energy Bohr orbit.



Since only certain frequencies of light were produced, only certain orbits must be possible.

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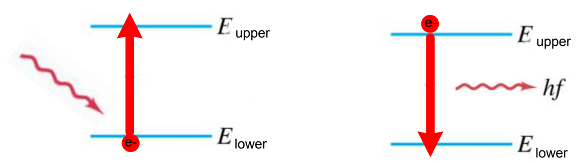
Emission Spectra and the Bohr Model

These possible energy states for atomic electrons were quantized – only certain values were possible. The spectrum could be explained as transitions from one level to another.

Electrons would only radiate when they moved between orbits, not when they stayed in one orbit.



5 According to Bohr, "n" stands for...

- A the number of cycles
- B the number of electrons
- C the energy level of the orbit
- D the number of orbits

5 According to Bohr, "n" stands for...

- A the number of cy
- B the number of el
- C the energy lev
- D the number of o

Answer

C

6 In the Bohr model of the atom an electron in its lowest energy state

- A is in the ground state
- B is farthest from the nucleus
- C is in an excited state
- D emits energy

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6 In the Bohr model of the atom an electron in its lowest energy state

- A is in the ground s
- B is farthest from t
- C is in an excited s
- D emits energy

Answer

A

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7 Which of the following best explains why excited atoms produce emission spectra and not continuous spectra?

- Not all atoms contain enough electrons to produce a continuous spectrum
- A continuous spectrum requires the movement of neutrons
- Electrons can only exist in certain stable orbitals of specific energies
- Electrons can exist and move anywhere around the nucleus and are not bound to a specific orbit

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Slide 27 (Answer) / 155

7 Which of the following best explains why excited atoms produce emission spectra and not continuous spectra?

- Not all atoms con a continuous spe
- A continuous sp neutrons
- Electrons can onl specific energies
- Electrons can exist a nucleus and are not bound to a specific orbit

Answer

C

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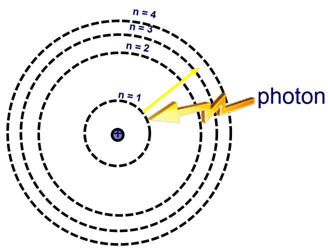
Emission Spectra and the Bohr Model

According to Bohr's model, first an electron is excited from its ground state by absorbing energy.



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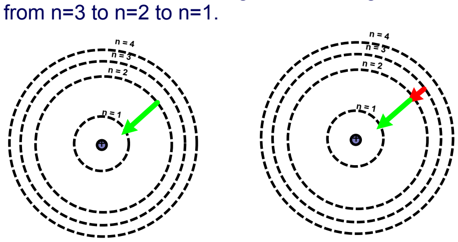
Emission Spectra and the Bohr Model

Once an electron is excited, it can take any number of routes back to its ground state, so long as it is releasing energy in discrete quantitized packets.

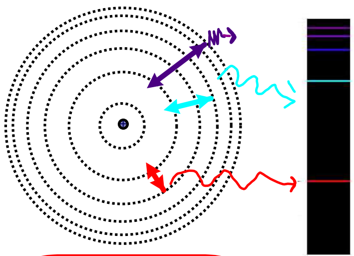
Here we see 2 separate emissions coming from the same electron. The electron can either go from n=3 right to n=1 or it can go from n=3 to n=2 to n=1.



Both are acceptable and both will occur.

Emission Spectrum of Hydrogen

Hydrogen atoms have one proton and one electron. The emission spectrum of hydrogen shows all of the different possible wavelengths of visible light emitted when an excited electron returns to a lower energy state.



Transition	λ light emitted
6 → 2	410 nm
4 → 2	486 nm
3 → 2	656 nm

Click here for Bohr model animation

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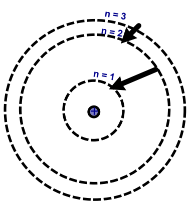
Emission Spectra and the Bohr Model

The difference in energy between consecutive orbits decreases as one moves farther from the nucleus.

E = h#   c =##



Transition	wavelength of spectral line produced (nm)	Energy (J)
3 --> 2	656	3.03×10^{-19}
2 --> 1	122	1.63×10^{-18}

$h = 6.626 \times 10^{-34}$ J*s

$c = 2.998 \times 10^{8}$ m*s^{-1}

Note in chemistry "#" represents frequency instead of "f"

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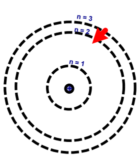
Emission Spectra and the Bohr Model

The energy differences between the Bohr orbits were found to correlate exactly with the energy of a particular spectral lines in the emission spectra of Hydrogen!



Energy of n = 3 = -2.417×10^{-19} J

Energy of n = 2 = -5.445×10^{-19} J

$\Delta E = (-2.417 \times 10^{-19}\ J) - (-5.445 \times 10^{-19}\ J)$

$\mathbf{\Delta E = 3.028 \times 10^{-19}\ J}$

Hydrogen emission spectrum

Red line wavelength (#)= 656.3 nm

E = hf or E = hc/#

E = 3.0×10^{-19} J

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Emission Spectra and the Bohr Model

The energy differences between the Bohr orbits were found to correlate exactly with the energy of a particular spectral lines in the emissi

Notes

Significant Figures

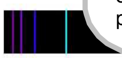
Significant figures allow you to know the precision with which the data was collected. More significant figures = more precise measurement.

When doing basic math operations on sets of data points, the resultant should always have the same number of significant figures as the least precise measurement.

7×10^{-19} J

5×10^{-19} J

$- (-5.445 \times 10^{-19}$ J)



ectrum

#)= 656.3 nm

E = hf or E = hc/#

E = 3.0×10^{-19} J

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8 Which of the following electron transitions would produce the highest energy spectral line?

- 5 --> 4
- 3 --> 2
- 4 --> 3
- 2 --> 1

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8 Which of the following electron transitions would produce the highest energy spectral line?

- 5 --> 4
- 3 --> 2
- 4 --> 3
- 2 --> 1

Answer

D

Slide 33 (Answer) / 155

9 The red spectral line is the Balmer series has a wavelength of 656.3 nm. What is the frequency of this light wave in gigahertz ($x10^9$)?

9 The red spectral line is the Balmer series has a wavelength of 656.3 nm. What is the frequency of this light wave in gigahertz ($x10^9$)?

Answer

4.6×10^{14} Hz
460000 GHz

10 The first ultraviolet spectral line is the Balmer series has a wavelength of 397.0 nm. What is the frequency of this light wave in gigahertz ($x10^9$)?

10 The first ultraviolet spectral line is the Balmer series has a wavelength of 397.0 nm. What is the frequency of this light wave in gigahertz ($x10^9$)?

Answer

$7.6x10^{14}$ Hz
760000 GHz

11 The energy of a photon that has a frequency 110 GHz is

- A 1.1×10^{-20} J
- B 1.4×10^{-22} J
- C 7.3×10^{-23} J
- D 1.3×10^{-25} J

11 The energy of a photon that has a frequency 110 GHz is

- A 1.1×10^{-20} J
- B 1.4×10^{-22} J
- C 7.3×10^{-23} J
- D 1.3×10^{-25} J

Answer

C

12 The frequency of a photon that has an energy of 3.7×10^{-18} J is

- A 5.6×10^{15} Hz
- B 1.8×10^{-16} Hz
- C 2.5×10^{-15} J
- D 5.4×10^{-8} J

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12 The frequency of a photon that has an energy of 3.7×10^{-18} J is

- A 5.6×10^{15} Hz
- B 1.8×10^{-16} Hz
- C 2.5×10^{-15} J
- D 5.4×10^{-8} J

Answer

A

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13 The energy of a photon that has a wavelength of 12.3 nm is

- A 1.51×10^{-17} J
- B 4.42×10^{-23} J
- C 1.99×10^{-25} J
- D 1.61×10^{-17} J

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Slide 38 (Answer) / 155

13 The energy of a photon that has a wavelength of 12.3 nm is

- A 1.51×10^{-17} J
- B 4.42×10^{23} J
- C 1.99×10^{-25} J
- D 1.61×10^{-17} J

Answer

D

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14 If the wavelength of a photon is halved, by what factor does its energy change?

- A 4
- B 2
- C 1/4
- D 1/2

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14 If the wavelength of a photon is halved, by what factor does its

- A 4
- B 2
- C 1/4
- D 1/2

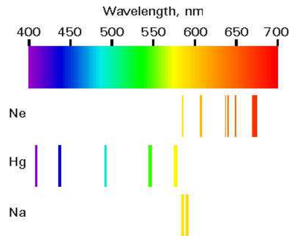
Answer

B

Emission Spectra and the Bohr Model

Due to the differing numbers of protons in the nucleus and number of electrons around them, each atom produces a unique emission spectrum after being energized.

Since the emission spectrum of each element is unique, it can be used to identify the presence of a particular element.



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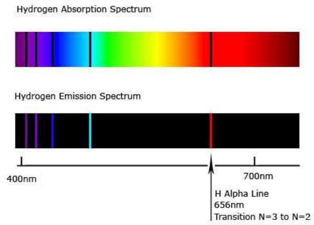
Absorption vs. Emission

Since electrons can only transition between orbits of set energies atoms must absorb energy at the same frequencies at which they emit energy.



As a result, monitoring which frequencies of light are absorbed can help us determine which element or molecule is present.

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15 The emission spectrum for Chlorine is shown below. Which of the following represents Chlorine's corresponding absorption spectrum?

A 

B 

C 

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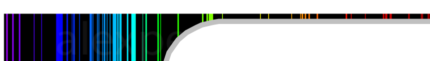
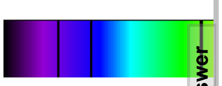
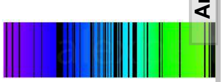
15 The emission spectrum for Chlorine is shown below. Which of the following represents Chlorine's corresponding absorption spectrum?



A 

B 

C 

Answer

B

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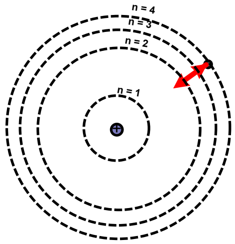
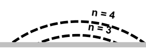
16 Does the picture below illustrate a photon emission or absorption?



- A Emission
- B Absorbtion
- C Neither
- D Both

16 Does the picture below illustrate a photon emission or absorption?



- A Emission
- B Absorbtion
- C Neither
- D Both

Answer

A

17 Which of the following is NOT true regarding the Bohr model of the atom?

- Electrons could exist only in certain quantized orbits around the atom
- As "n" becomes greater, the energy of the orbit is greater also
- When returning from an excited state, an electron can can only move between the set Bohr orbits
- All of these are true

17 Which of the following is NOT true regarding the Bohr model of the atom?

- Electrons could exi... ...its around the atom
- As "n" becomes ... greater also
- When returning fr... can can only mov...
- All of these are tru...

Answer

D

The Problem with the Bohr Model

Bohr's model answered a lot of questions but it still had some problems.

1. Multi-electron atoms did not have the energy levels predicted by the Bohr model.

2. Double and triple bands appear in emission spectra. The model does not have an explanation for why some energy levels are very close together.

It takes quantum mechanics to provide a more accurate picture of the atom.

Quantum Mechanics

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Bohr Model

While a big step forward, Bohr's model was only useful in predicting the frequency of spectral line for atoms that had one electron, like hydrogen or certain ionized atoms.

The idea that the electron was a particle in orbit around the nucleus, but with wavelike properties that only allowed certain orbits, worked only for hydrogen.

Semi-classical explanations failed except for hydrogen. It turned out that only a lucky chance let it work even in that case.

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A Particle or a Wave?

Our goal was to explain why electrons in an atom don't fall into the nucleus. An electron, as a charged particle, would fall in because of Newton's Second Law.

#**F = ma**

Taking into account that light exhibits properties of both a particle and a wave, in 1924, French physicist Louis de Broglie asked:

"If light can behave like a wave or a particle, can matter also behave like a wave?"

He found that amazingly, it does!

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* Wavelength of Matter

de Broglie proposed matter might also behave like a wave and have a wavelength associated with its momentum and mass.

He earned a Nobel Prize for a simple derivation of recent discoveries about energy and matter, setting Einstein's formula relating energy and matter equal to Planck's formula relating energy and frequency of a wave:

$E = mc^2$ $E = h\nu$

$$mc^2 = h\nu$$

Since real particles don't travel at the speed of light $c^2 = v^2$

$$mv^2 = h\nu$$

$$mv^2 = h\frac{v}{\lambda} \qquad \nu = \frac{v}{\lambda}$$

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

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

* Wave Nature of Matter

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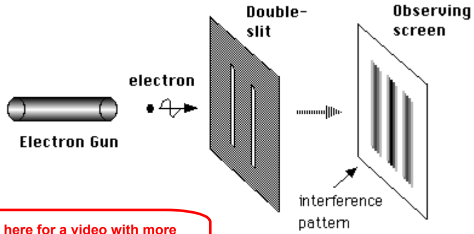
The de-Broglie hypothesis that particles have wave-like properties needed to be supported by experiment.

In a Nobel Prize winning experiment, Davisson and Germer of Bell Labs found that electrons could be diffracted (remember the two slit experiment) just like light waves.



Click here for a video with more explanation of all this!

* The Most Amazing Experiment Ever!

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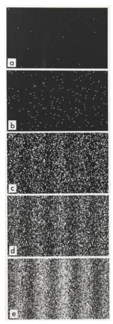
These photos show electrons being fired *one at a time* through two slits.

Each exposure was made after a slightly longer time. The same pattern emerges as was found by light.

Each individual electron must behave like a wave and pass through both slits. But each electron must be a particle when it strikes the film, or it wouldn't make one dot on the film, it would be spread out.



This one picture shows that matter acts like both a wave and a particle.

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* 18 What is the wavelength of a 0.25 kg ball traveling at 20 m/s?

*

18 What is the wavelength
traveling at 20 m/s?

Answer

1.26×10^{-34} m

Slide 53 (Answer) / 155

*

19 What is the wavelength of an 80 kg person
running 4.0 m/s?

Slide 54 / 155

*

19 What is the wavelength
running 4.0 m/s?

Answer

2.0×10^{-36} m

Slide 54 (Answer) / 155

*

20 What is the wavelength of the matter wave associated with an electron ($m_e = 9.1 \times 10^{-31}$ kg) moving with a speed of 2.5×10^7 m/s?

*

20 What is the wavelengt
associated with an el
moving with a speed

Answer

2.9×10^{-11} m

*

21 What is the wavelength of the matter wave associated with an electron ($m_e = 9.1 \times 10^{-31}$ kg) moving with a speed of 1.5×10^6 m/s?

*

21 What is the wavelength [obscured] associated with an el[obscured] moving with a speed [obscured]

Answer

4.9×10^{-11} m

Slide 56 (Answer) / 155

*

Quantum Mechanics – A New Theory

Quantum mechanics is a branch of physics which provides a mathematical description of wave-particle duality, and successfully explains the following 2 ideas:

(1) the energy states in complex atoms and molecules

(2) the relative brightness of spectral lines

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

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*

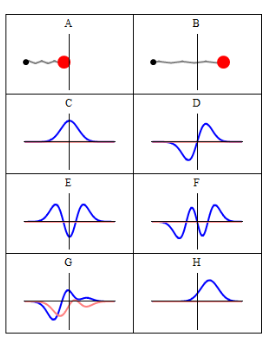
The Wave Function

An electromagnetic (light) wave is made of oscillating electric and magnetic fields.

What is oscillating in an electron or matter wave?

The **wave function**, **Ψ** (psi) describes the state and behavior of an electron. The two fields of the wave are noted in blue and red in this animation.

Each wave frequency is proportional to the possible energy level of the oscillator.



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Slide 59 / 155

*

Interpretation of the Wave Function (Ψ)

The square of the wave function at any point is proportional to the number of electrons expected to be found there.

$\Psi^2 \propto \#$ electrons

For a single electron, the wave function is the probability of finding the electron at that point.

$\Psi =$ Probability of finding electron

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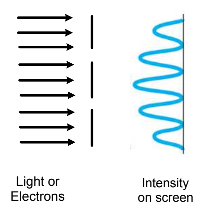
*

The Double-Slit Experiment

Recall the interference pattern 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.

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*

22 The probability of finding an electron at a specific location is directly proportional to:

- A its energy.
- B its momentum.
- C its wave function.
- D the square of its wave function.

*

22 The probability of finding an electron at a specific location is directly proportional to:

- A its energy.
- B its momentum.
- C its wave function
- D the square of its

Answer

C

23 It is possible to know the exact path of an electron.

- True
- False

23 It is possible to know the exact path of an electron.

- True
- False

Answer

False

The Heisenberg Uncertainty Principle

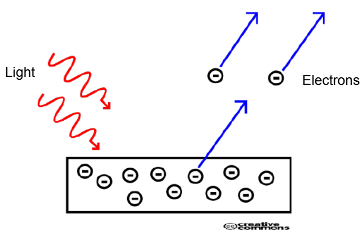
Quantum mechanics tells us there are inherent limits to measurement.

This is not because of the limits of our instruments, rather it is due to the wave-particle duality, and to the interaction between the observing equipment and the object being observed.

With this in mind, in 1926 a man named Werner Heisenberg proposed what's known as the **Heisenberg Uncertainty Principle.**

Photoelectric Effect

Recall the Photoelectric Effect, which shows light of specific frequencies incident upon certain polished metals emits electrons. This demonstrates the particle nature of light.



https://www.njctl.org/video/?v=DiSiRhw1fII

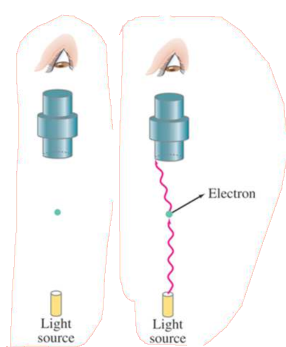
The Heisenberg Uncertainty Principle

Try to find the position of an electron with a powerful microscope.

At least one photon must scatter off the electron and enter the microscope.

However, in doing so, it will transfer some of its momentum to the electron.

Electrons are so small that the very act of observing their position changes their position.



The Heisenberg Uncertainty Principle

Imagine you are in a large, dark warehouse with a bunch of marbles rolling around on the floor. You can't see or hear and are given a walking stick to try to locate the position of the marbles.

What would happen every time you tried to measure the position of a marble?

If we ignore friction and allow the marbles to fly around the room in 3 dimensions (like electrons actually do) could we ever really know where the marble is EXACTLY?

*

The Heisenberg Uncertainty Principle

This can also be written as the relationship between the uncertainty in time and the uncertainty in energy:

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

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

It also says that conservation of energy can be violated if the time is short enough.

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24 The idea that the position and momentum of an electron cannot measured with infinite precision is referred to as the

- A exclusion principle.
- B uncertainty principle.
- C photoelectric effect.
- D principle of relativity.

Slide 70 / 155

24 The idea that the position and momentum of an electron cannot measured with infinite precision is referred to as the

- A exclusion princi
- B uncertainty prin
- C photoelectric ef
- D principle of relat

Answer

B

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25 If the accuracy in measuring the position of a particle increases, the accuracy in measuring its momentum will

- A increase.
- B decrease.
- C remain the same.
- D be uncertain.

25 If the accuracy in measuring the position of a particle increases, the accuracy in measuring its momentum will

- A increase.
- B decrease.
- C remain the sa
- D be uncertain.

Answer

B

26 If the accuracy in measuring the momentum of a particle increases, the accuracy in measuring its position will

- A increase.
- B decrease.
- C remain the same.
- D be uncertain.

Slide 72 (Answer) / 155

26 If the accuracy in measuring the momentum of a particle increases, the accuracy in measuring its position will

- A increase.
- B decrease.
- C remain the sa
- D be uncertain.

Answer

B

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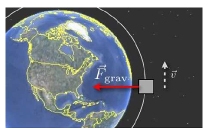
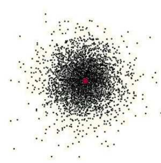
Probability vs Determinism

As you know, the world of Newtonian mechanics is a deterministic one.
If you know the forces on an object and its initial velocity, you can predict where it will go.



Quantum mechanics is very different.
You can predict what most electrons will do on average, but you can have no idea what any individual electron will do.



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Classical vs Quantum Mechanics

In classical physics, predictions about how objects respond to forces are based on Newton's Second Law:

#F = ma

In quantum physics, this no longer works; predictions are based on Schrödinger's Wave Equation.

H# = E#

Where H is the Hamiltonian operator, E is the energy, and # is the wave function.

Schrödinger's Wave Equation

H# = E#

Solving this equation is well beyond this course. And only probabilities of outcomes can be determined…you cannot specifically determine what will happen in each case.

However, this equation has been solved for many specific cases and we will be using those solutions to understand atoms, molecules, and chemical bonds.

Schrödinger and his cat?

Erwin Schrödinger received the Nobel Prize in Physics in 1933 for the development of the Schrödinger Equation.

Additionally he is known for his famous thought experiment where he applied quantum mechanics to everyday objects... specifically a cat.

click here for a short explanation of "Schrodinger's Cat"

27 Quantum mechanics provides a mathematical definition for the:

- A wave-like properties of electrons only.
- B particle-like properties of electrons only
- C classic Newtonian forces that govern atoms
- D the wave-particle duality of electrons

Slide 77 (Answer) / 155

27 Quantum mechanics provides a mathematical definition for the:

- A wave-like properti
- B particle-like prop
- C classic Newtonia
- D the wave-partic

Answer

D

Slide 78 / 155

28 Quantum mechanics allows to you predict exactly what an electron will due.

- True
- False

Slide 78 (Answer) / 155

28 Quantum mechanics allows to you predict exactly what an electron will due.

- True
- False

Answer

False

The Quantum Model

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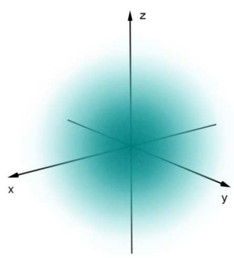
of Contents

Quantum-Mechanical Model of the Atom

Since we cannot say exactly where an electron is, the Bohr picture of the atom, with its electrons in neat orbits, cannot be correct.

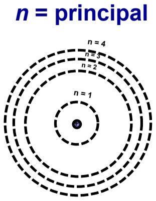
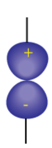
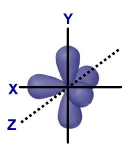
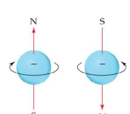
Quantum theory describes an electron probability distribution; this figure shows the distribution for the ground state of hydrogen.

In this picture, the probability of finding an electron somewhere is represented by the density of dots at that location.



Quantum Numbers

Solutions to Schrodinger's Wave Equation take the form of sets of numbers. There are four different quantum numbers: **n**, **l**, **m_l**, **m_s** needed to specify the state or probable location of an electron in an atom.

***n* = principal**	***l* = angular**	***m_l* = magnetic**	***m_s* = spin**
			 - +
energy level/ distance from nucleus	shape of orbital	orientation of orbital in space	direction of electron spin

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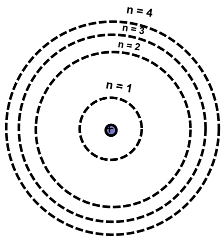
(n): Principal Quantum Number

An orbital is a region of space where an electron is most likely to be found.

The principal quantum number, ***n***, describes the energy level of the orbital, often called the energy shell.

The values of n are integers greater than or equal to 1:

$$n \geq 1$$



In general, the larger the value of n, the farther from the nucleus the electron should be found.

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29 The principal quantum number, n, determines the ____________ of the orbital.

- A Orientation
- B Energy
- C Shape
- D Capacity

Slide 83 (Answer) / 155

29 The principal quantum number, n, determines the ____________ of the orbital.

- A Orientation
- B Energy
- C Shape
- D Capacity

Answer

B

30 As *n* increases, the orbital energy _________ .

- A Increases
- B Decreases
- C Remains constant
- D Increases then decreases

30 As *n* increases, the orbital energy _________ .

- A Increases
- B Decreases
- C Remains co
- D Increases th

Answer

A

(*l*): Angular Quantum Number
(m_l): Magnetic Quantum Number

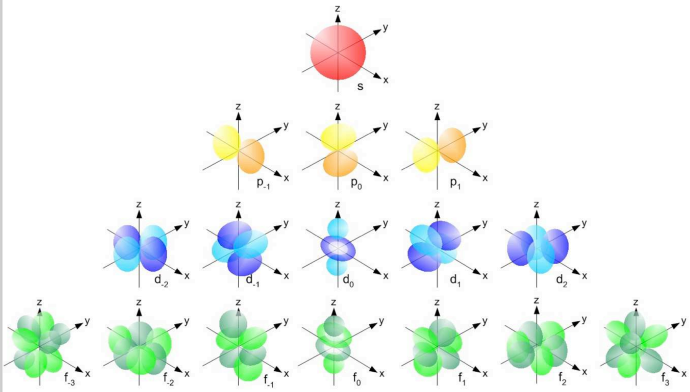
Each orbital region or **subshell** has a very specific shape based on the energy of the electrons occupying them and a specific orientation in space.

Quantum number ***l*** designates the shape of the orbital.

There are four shapes of orbitals: ***s***,***p***,***d***,***f***

Quantum number $\boldsymbol{m_l}$ designates the orientation of the orbital in space.

Electron Orbital Shape and Orientations



http://chemwiki.ucdavis.edu/@api/deki/files/4826/=Single_electron_orbitals.jp

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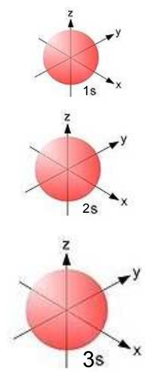
The *s* Subshell

s orbitals are spherical in shape.The radius of the sphere increases with the value of *n.*

If you are looking for an electron in an s orbital, the direction you look in doesn't really matter, they have only one orientation in space.



If *l* = s shape
***m_l* = 1 orientation**
1 orbital per energy level

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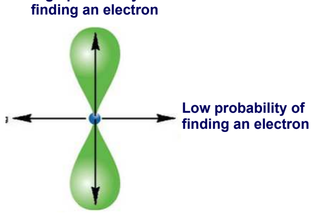
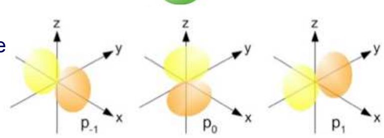
The *p* Subshell

p orbitals have two lobes with a node between them.

For *p* orbitals, the amount of electron density and the probability of finding an electron depends on both the *distance* from the center of the atom, as well as the *direction.*



The *p* subshell has 3 possible arrangements in space, so it can have 3 possible orbitals.



***l* = p shape**
***m_l* = 3 orientations**
3 orbitals per energy level

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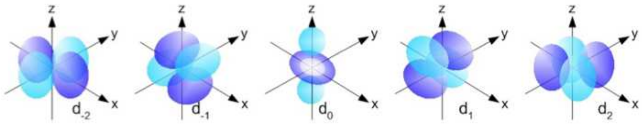
The *d* Subshell

d orbitals have more complex shapes.
There are 5 possible orientations in space,
so there are 5 possible d orbitals.



l **= d shape**
m_l **= 5 orientations**
5 orbitals per energy level

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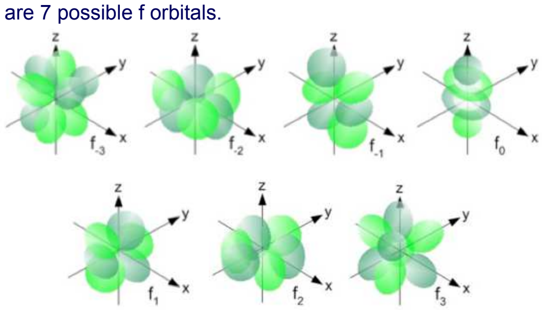
The *f* Subshell

There are 7 possible f orbitals.



l **= f shape**
m_l **= 7 orientations**
7 orbitals per energy level

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31 The quantum number, *l*, determines the ____________ of the orbital.

- A Orientation
- B Energy
- C Shape
- D Capacity

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Slide 91 (Answer) / 155

31 The quantum number, *l*, determines the _____________ of the orbital.

- A Orientation
- B Energy
- C Shape
- D Capacity

Answer

C

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32 The magnetic quantum number, m_l, determines the _____________ of the orbital.

- A Orientation
- B Energy
- C Shape
- D Capacity

Slide 92 (Answer) / 155

32 The magnetic quantum number, m_l, determines the _____________ of the orbital.

- A Orientation
- B Energy
- C Shape
- D Capacity

Answer

A

33 A(n) ___ orbital is lobe-shaped

- A s
- B p
- C d
- D f

33 A(n) ___ orbital is lobe-shaped

- A s
- B p
- C d
- D f

Answer

B

34 An s orbital has _______ possible orientations in space.

- A 1
- B 3
- C 5
- D 7

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34 An s orbital has _______ possible orientations in space.

- A 1
- B 3
- C 5
- D 7

Answer

A

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35 An f orbital has _______ possible orientations in space.

- A 1
- B 3
- C 5
- D 7

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35 An f orbital has _______ possible orientations in space.

- A 1
- B 3
- C 5
- D 7

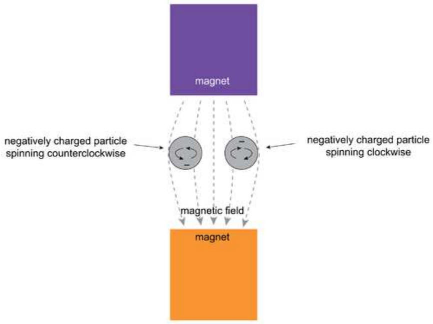
Answer

D

Spin Quantum Number, m_s

In the 1920s, it was discovered that two electrons in the same orbital do not have exactly the same energy.

This led to a fourth quantum number, the spin quantum number, m_s.



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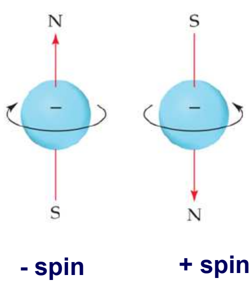
Spin Quantum Number, m_s

The “spin” of an electron describes its magnetic field, which affects its energy.

The spin quantum number can be positive or negative.

This implies that electrons are in some way able to pair up, even though they repel each other due to the electromagnetic force.

Each orbital can therefore hold a maximum of 2 electrons.



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36 The spin quantum number, m_s

- A can only have two values
- B relates to the spin of the electron
- C relates to the spin of the atom
- D Both A & B

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Slide 98 (Answer) / 155

36 The spin quantum number, m_s

- A can only have two values
- B relates to the sp
- C relates to the s
- D Both A & B

Answer

D

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37 Electrons within the same orbital must have

- A the same spin
- B no spin
- C opposite spins
- D electrons cannot occupy the same orbital

Slide 99 (Answer) / 155

37 Electrons within the same orbital must have

- A the same spin
- B no spin
- C opposite spins
- D electrons cann
orbital

Answer

C

*

The Four Quantum Numbers

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

Principal quantum number designates energy or shell level
$n = 1, 2, 3....$

Angular quantum number designates orbital shape:
s = 0, p = 1,d = 2, f = 3 ***$l = n-1$***

Magnetic quantum number designates orbital orientation
$-l \geq m_l \leq l$

Spin quantum number designates electron spin
$m_s = +1/2$ or $-1/2$

Energy Levels and Sublevels

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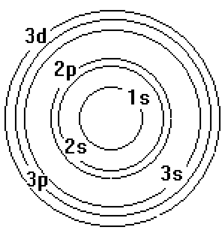

Some combinations of Quantum Numbers are impossible:

If n = 1, an electron can only occupy an s subshell.

If n = 2, an electron can only occupy s or p subshells.

If n = 3, an electron can only occupy s, p, or d subshells

If n = 4 an electron can occupy s, p, d, or f subshells

Quantum Numbers Subshells

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Orbitals with the same value of *n* form a shell.
Different orbital types within a shell are subshells.

n	subshell	# of orbitals	total # of orbitals	total # of electrons
1	1s	1	1	2
2	2s 2p	1 3	4	8
3	3s 3p 3d	1 3 5	9	18
4	4s 4p 4d 4f	1 3 5 7	16	32

Slide 103 / 155

38 If n = 1 an electron can occupy which of the subshells?

- A 1s
- B 2s
- C 2p
- D 3s

Slide 103 (Answer) / 155

38 If n = 1 an electron can occupy which of the subshells?

- A 1s
- B 2s
- C 2p
- D 3s

Answer

A

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39 n = 1 can hold a maximum of ___ electrons

39 n = 1 can hold a maximum of ___ electrons

Answer

2

40 What is the maximum number of electrons that can occupy the n = 4 shell?

40 What is the maximum number of electrons that can occupy the n = 4 shell?

Answer

32

41 An electron is in the 6f state. Determine the principal quantum number.

41 An electron is in the 6f state. Determine the principal quantum number.

Answer

6

42 An electron is in the 6d state. How many electrons are allowed in this state?

42 An electron is in the 6d state. How many electrons are allowed in this state?

Answer

10

Slide 107 (Answer) / 155

**
43 An electron is in the 6f state. Determine the angular quantum number.

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**
43 An electron is in the 6f state. Determine the angular quantum number.

Answer

4

Slide 108 (Answer) / 155

Slide 109 / 155

* *
44 How many possible sets of quantum numbers or electron states are there in the 4d subshell?

Slide 109 (Answer) / 155

* *
44 How many possible sets of quantum numbers or electron states are there in the 4d subshell?

Answer

10

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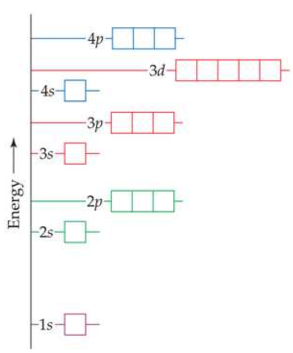
* *
45 How many electrons will fit into a subshell with the quantum numbers n = 4, l = 3?

* *
45 How many electrons will fit into a subshell with the quantum numbers n = 4, l = 3?

Answer

14

Energies of Orbitals



As the number of electrons increases, so does the repulsion between them.

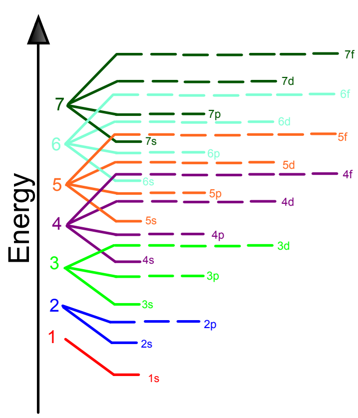
Complex atoms contain more than one electron, so the interaction *between* electrons must be accounted for in the energy levels.

This means that the energy depends on both n (the shell) and *l* (the subshell).

Energies of Orbitals

Notice that some sublevels on a given n level may have less energy than sublevels on a lower n level.

For example: the energy of 4s is less than the energy of 3d.



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46 The energy of an orbital depends on...

- A n
- B n and l
- C n, l, and m_l
- D l and m_l

Slide 113 (Answer) / 155

46 The energy of an orbital depends on...

- A n
- B n and l
- C n, l, and m_l
- D l and m_l

Answer

B

Slide 114 / 155

47 Which of the follows correctly sequences the orbitals in order of increasing energy?

- A 1s<2s<2p<3s<3p<3d<4s
- B 1s<2s<2p<3s<3p<4s<3d
- C 1s<2s<2p<2d<3s<3p<3d<4s
- D 1s<2s<2p<3s<4s<3p<3d

Slide 114 (Answer) / 155

47 Which of the follows correctly sequences the orbitals in order of increasing energy?

- A 1s<2s<2p<3s<3p<3d<4s
- B 1s<2s<2p<3s<3p
- C 1s<2s<2p<2d<3
- D 1s<2s<2p<3s<

Answer

B

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Electron Configurations

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Orbital Diagrams

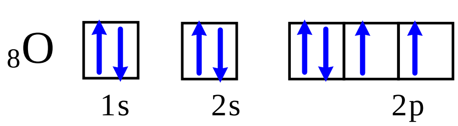
Orbital diagrams are a shorthand way to illustrate the energy levels of electrons.

Each box in the diagram represents one orbital.

Orbitals on the same subshell are drawn together.

Arrows represent the electrons.

The direction of the arrow represents the relative spin of the electron (+ or -).



Energies of Orbitals

Electron Orbital Diagram

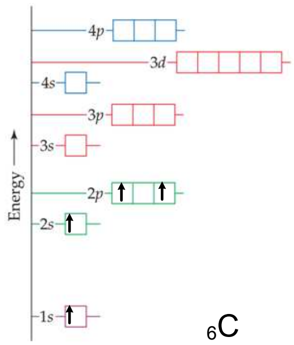
Orbital diagrams can also be drawn vertically to illustrate increasing energy.

To complete an orbital diagram you must first know how many electrons the atom has.

In a neutral atom:

# of electrons = # of protons

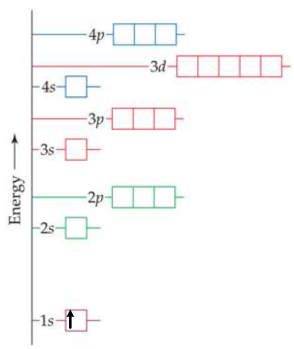
so the # of electrons will be the same as the atomic number.



$_6C$

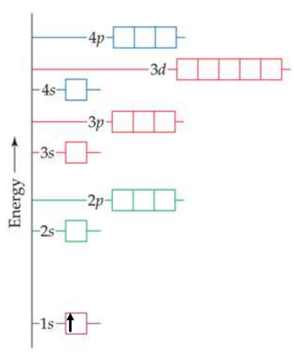
48 In an electron orbital diagram, an individual box represents?

- A Energy level
- B Orbital
- C The electron
- D The electron spin



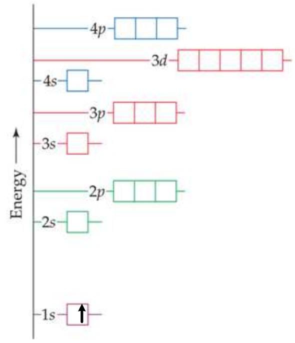
49 In an electron orbital diagram, which symbol represents an electron?

- A □
- B ↑
- C
- D both B and C



50 In an electron orbital diagram, the three orbitals together  indicate each orbital occupies

- A The same energy level
- B The same electrons
- C Different energy levels
- D Different electron spins



3 Rules for Filling Electron Orbitals

Aufbau Principle

Electrons are added one at a time to the lowest energy orbitals available until all the electrons of the atoms have been accounted for.

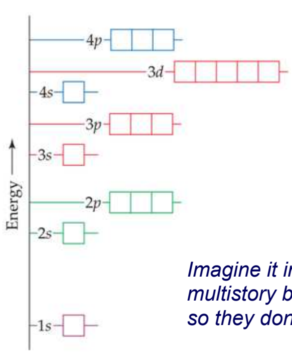
Pauli Exclusion Principle

An orbital can hold a maximum of two electrons. To occupy the same orbital, two electrons must spin in the opposite direction.

Hund's Rule

If two or more orbitals of equal energy are available, electrons will occupy them singly before filling orbitals in pairs.

Aufbau Principle



Aufbau takes its name from a German word meaning "building up".

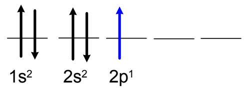
Developed in the 1920s by Bohr and Pauli and states that Electrons fill the lowest energy orbitals first.

Imagine it in terms of Lazy Tenants - tenants in a multistory building fill in from the ground level up, so they don't have to walk up stairs

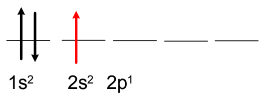
Pauli Exclusion Principle

No two electrons in the same atom can have exactly the same energy.

correct



incorrect



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

(m_s = + or -)

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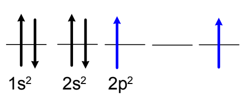
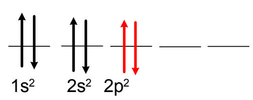
Hund's Rule

Every orbital in a subshell is singly occupied with one electron before any one orbital is doubly occupied, and all electrons in singly occupied orbitals have the same spin.

correct



incorrect



Think about the *Empty Bus Seat Rule*. People will not sit next to each other on a bus until all the seats are taken up

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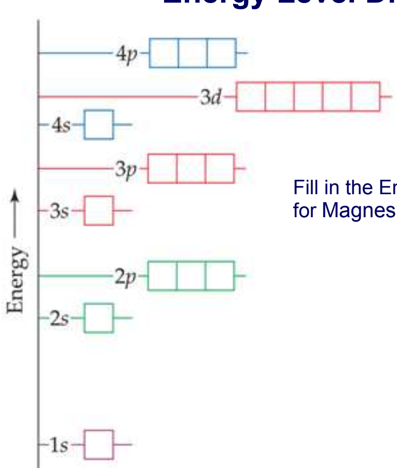
Energy Level Diagram



Fill in the Energy Level Diagram for Magnesium, Mg.

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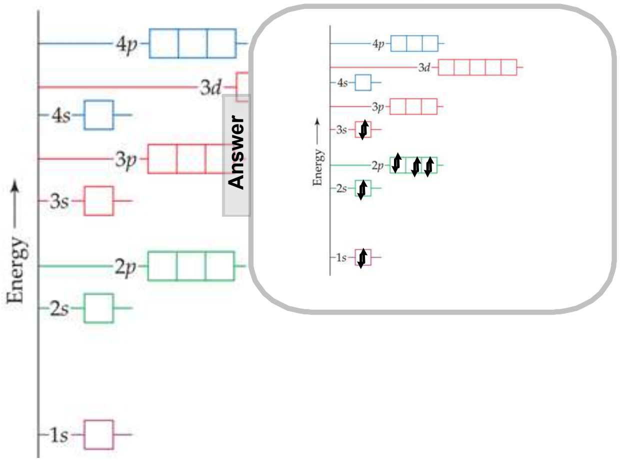
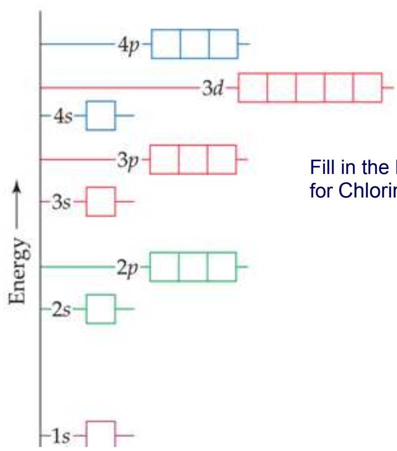
Energy Level Diagram



Slide 125 (Answer) / 155

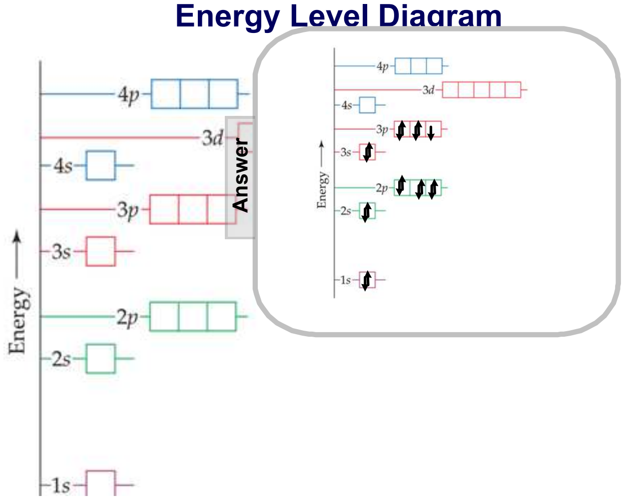
Energy Level Diagram



Fill in the Energy Level Diagram for Chlorine, Cl.

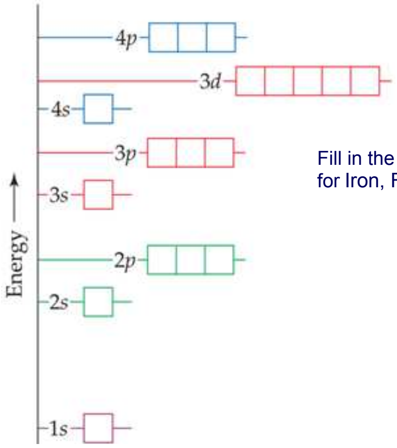
Slide 126 / 155

Energy Level Diagram



Slide 126 (Answer) / 155

Energy Level Diagram



Fill in the Energy Level Diagram for Iron, Fe.

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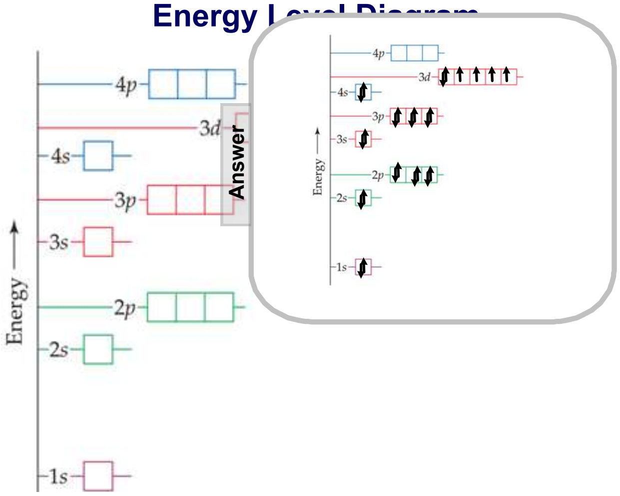
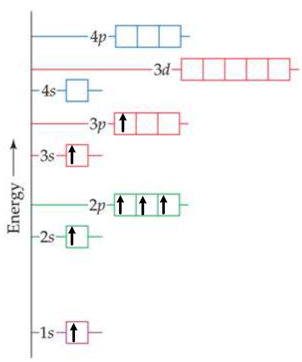
Energy Level Diagram



Slide 127 (Answer) / 155

51 The orbital diagram below depicts electrons in which element?

- A Oxygen
- B Sodium
- C Aluminum
- D Iron



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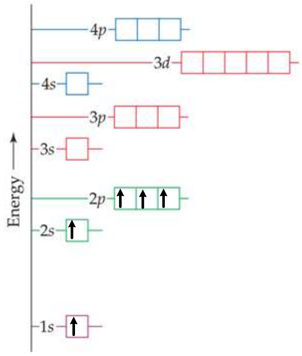
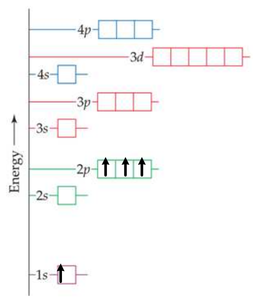
52 The orbital diagram below depicts electrons in which element?

- A Boron
- B Carbon
- C Nitrogen
- D Neon



53 What is wrong with the electron orbital diagram below?

- A Electrons are not filling lower energy orbitals first - violation of the Aufbau Principle.
- B Two electrons occupying the same orbital have the same spin - violation of the Pauli Exclusion Principle.
- C Some orbitals are double occupied by electrons before every orbital has at least one electron - violation of Hund's Rule.
- D This orbital diagram is correct.



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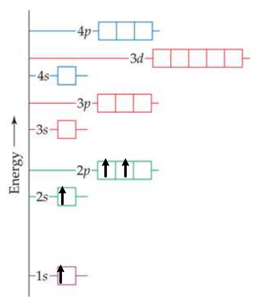

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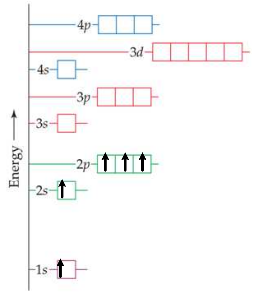
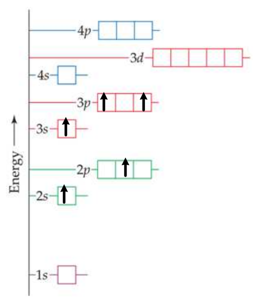


Slide 132 / 155

56 What is wrong with the electron orbital diagram below?

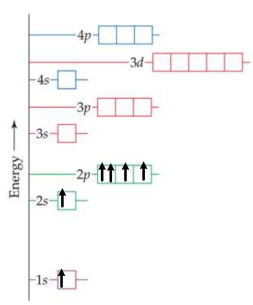
- A Electrons are not filling lower energy orbitals first - violation of the Aufbau Principle.
- B Two electrons occupying the same orbital have the same spin - violation of the Pauli Exclusion Principle.
- C Some orbitals are double occupied by electrons before every orbital has at least one electron - violation of Hund's Rule.
- D This orbital diagram is correct.



Slide 133 / 155

57 What is wrong with the electron orbital diagram below?

- A Electrons are not filling lower energy orbitals first - violation of the Aufbau Principle.
- B Two electrons occupying the same orbital have the same spin - violation of the Pauli Exclusion Principle.
- C Some orbitals are double occupied by electrons before every orbital has at least one electron - violation of Hund's Rule.
- D This orbital diagram is correct.



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Electron Configurations

Electron configurations show the distribution of all electrons in an atom.

Each component consists of:

A number denoting the shell

$$4p^5$$

Electron Configurations

Electron configurations show the distribution of all electrons in an atom.

Each component consists of:

A number denoting the shell,
A letter denoting the type of subshell

$$4p^5$$

Electron Configurations

Electron configurations show the distribution of all electrons in an atom.

Each component consists of:

- A number denoting the shell,
- A letter denoting the type of subshell, and
- A superscript denoting the number of electrons inthose orbitals.

$$4p^5$$

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Slide 139 / 155

Electron Configuration of Sodium

For example, here is the ground-state configuration of sodium:

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

All of the superscript numbers add up to the total number of electrons. Remember in a neutral atom the # of electrons = # of protons

$^{23}_{11}Na$

Sodium Atom

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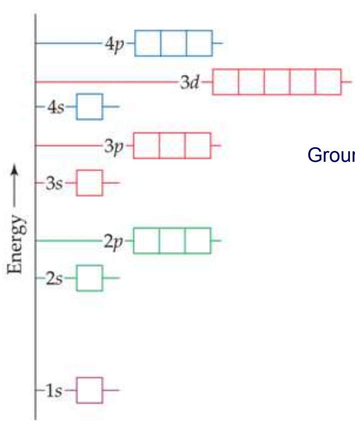
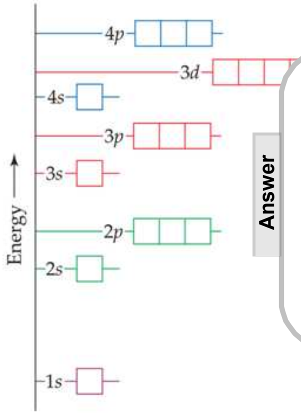
Practice



Write the Ground State Electron Configuration for Phosphorous, P.
Electron Configuration

Slide 140 (Answer) / 155

Practice



Answer

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

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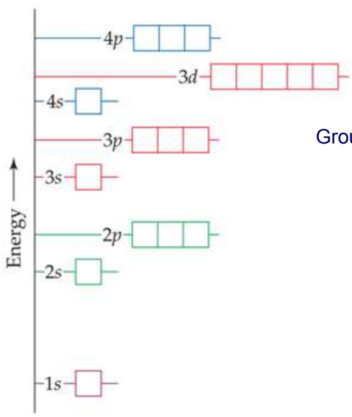
Practice

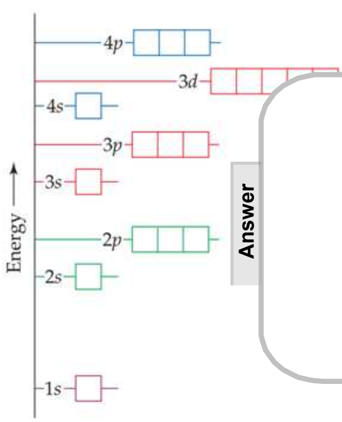


Write the
Ground State Electron Configuration
for Calcium, Ca.

Electron Configuration

Slide 141 (Answer) / 155

Practice



Answer

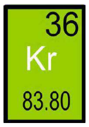
$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$

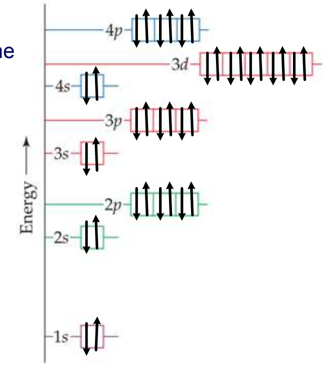
Electron Configuration of Krypton

Electron configurations are always written based on the energy level of the subshell not the shell.

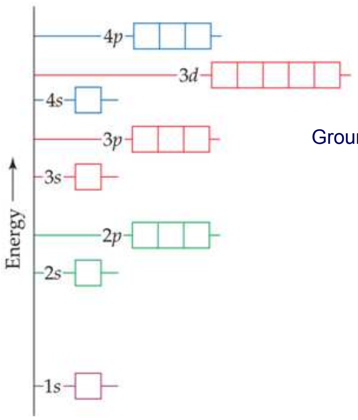
For example, here is the ground-state configuration of krypton:

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ \mathbf{4s^2\ 3d^{10}}\ 4p^6$





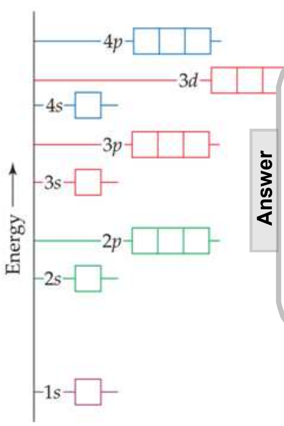
Practice



Write the
Ground State Electron Configuration
for Titanium, Ti

Electron Configuration

Practice

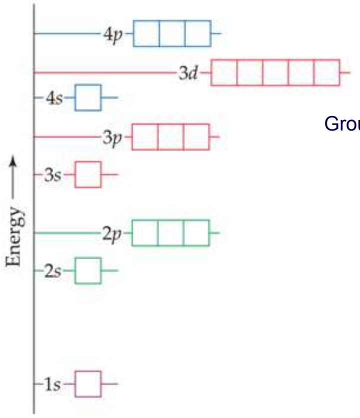


Answer

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$

Slide 144 / 155

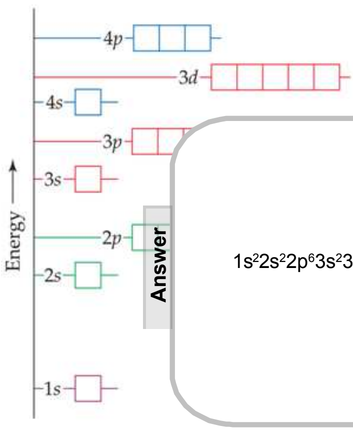
Practice



Write the
Ground State Electron Configuration
for Bromine, Br.

Slide 144 (Answer) / 155

Practice



Write the
n Configuration
Br.

Answer

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^5$

Slide 145 / 155

58 What is the electron configuration for Li ?

- A $1s^3$
- B $1s^1 2s^2$
- C $1s^2 2s^1$
- D $1s^2 1p^1$

58 What is the electron configuration for Li ?

- A $1s^3$
- B $1s^1 2s^2$
- C $1s^2 2s^1$
- D $1s^2 1p^1$

Answer

C

59 Which of the following is the correct electron configuration for Potassium (K)?

- A $1s^22s^23s^23p^64s^2$
- B $1s^22s^23s^23p^6$
- C $1s^22s^22p^6$
- D $1s^22s^22p^63s^23p^64s^1$

59 Which of the following is the correct electron configuration for Potassium (K)?

- A $1s^22s^23s^23p^64s^2$
- B $1s^22s^23s^23p^6$
- C $1s^22s^22p^6$
- D $1s^22s^22p^63s^23p^64s^1$

Answer

D

60 A neutral atom has an electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^1$. What is its atomic number?

- A 5
- B 11
- C 13
- D 20

60 A neutral atom has an electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^1$. What is its atomic number?

- A 5
- B 11
- C 13
- D 20

Answer

C

61 A neutral atom has the following electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$. What element is this?

- A zinz
- B copper
- C arsenic
- D germanium

61 A neutral atom has the following electron configuration: $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^3$. What element is thi

- A zinz
- B copper
- C arsenic
- D germanium

Answer

C

62 A neutral atom has an electron configuration of $1s^2 2s^2 2p^6$. If a neutral atom gains one additional electron, what is the ground state configuration?

- A $1s^2 2s^2 2p^6 3s^1$
- B $1s^2 2s^2 2p^7$
- C $1s^2 2s^3 2p^6$
- D none of the given answers

62 A neutral atom has an electron configuration of $1s^2 2s^2 2p^6$. If a neutral atom gains one additional electron, wh
configuration?

- A $1s^2 2s^2 2p^6 3s^1$
- B $1s^2 2s^2 2p^7$
- C $1s^2 2s^3 2p^6$
- D none of the give

Answer

A

*
63 Which of the following would be the correct electron configuration for a Mg^{2+} ion?

- A $1s^2 2s^2 3s^2 3p^6 4s^2$
- B $1s^2 2s^2 3s^2 3p^6$
- C $1s^2 2s^2 2p^6$
- D $1s^2 2s^2 2p^6 3s^2$

*
63 Which of the following would be the correct electron configuration for a Mg^{2+} ion?

- A $1s^2 2s^2 3s^2 3p^6 4s^2$
- B $1s^2 2s^2 3s^2 3p^6$
- C $1s^2 2s^2 2p^6$
- D $1s^2 2s^2 2p^6 3s^2$

Answer

C

*
64 Which of the following would be the correct electron configuration for a Cl^- ion?

- A $1s^2 2s^2 2p^6 3s^2 3p^6$
- B $1s^2 2s^2 3s^2 3p^5$
- C $1s^2 2s^2 2p^6$
- D $1s^2 2s^2 2p^6 3s^1$

*
64 Which of the following would be the correct electron configuration for a Cl^- ion?

- A $1s^22s^22p^63s^23p^6$
- B $1s^22s^23s^23p^5$
- C $1s^22s^22p^6$
- D $1s^22s^22p^63s^1$

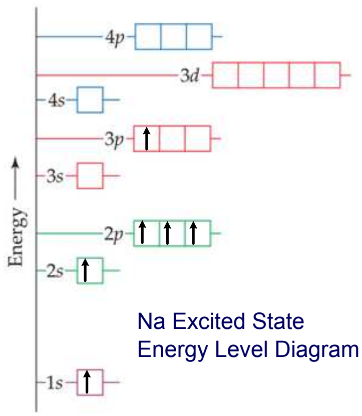
Answer

A

Slide 151 (Answer) / 155

*
Energy Level Diagram - Excited State

In a sodium-vapor lamp electrons in sodium atoms are excited to the 3p level by an electrical discharge and emit yellow light as they return to the ground state.



Na Excited State Energy Level Diagram

Slide 152 / 155

*
65 Which of the following represents an excited state electron configuration for Sodium (Na)?

- A $1s^22s^22p^63s^1$
- B $1s^22s^22p^7$
- C $1s^22s^22p^63p^1$
- D none of the given answers

Slide 153 / 155

*

65 Which of the following represents an excited state electron configuration for Sodium (Na)?

- A $1s^2 2s^2 2p^6 3s$
- B $1s^2 2s^2 2p^7$
- C $1s^2 2s^2 2p^6$
- D none of the

Answer

C

*

66 Which of the following represents an excited state electron configuration for Magnesium (Mg)?

- A $1s^2 2s^2 2p^6 3s^2$
- B $1s^2 2s^2 2p^7 3s^1$
- C $1s^2 2s^2 2p^6 3s^1 3p^1$
- D none of the above

*

66 Which of the following represents an excited state electron configuration for Magnesium (Mg)?

- A $1s^2 2s^2 2p^6 3$
- B $1s^2 2s^2 2p^7 3$
- C $1s^2 2s^2 2p$
- D none of the

Answer

C