Emission of Light:
Discharge Lamps & Flame Tests[1]

Objectives

At the end of this activity you should be able to:

- Describe how discharge lamps emit photons following electrical excitation of gaseous atoms.
- Discuss the inter-dependence of scientific and technological developments. Specifically, how the technology of discharge lamps is connected to Bohr's model of the atom and line spectra.
- Describe how thermal energy may lead to the emission of photons, and how this is accomplished in flame tests.
- Write the electron configuration for many-electron atoms in their ground-state.
- Write the electron configuration of ions.
- Understand the meaning of ionization energy and how it is related to the spacing of electronic energy levels.
- Relate the concept of effective nuclear charge to the spacing of electronic energy levels for sodium and neon.

Introduction

When light is emitted from a single element (like gaseous hydrogen) and passed through a prism only a small number of discrete lines are observed. Atomic models account for this phenomenon by proposing that an electron absorbs energy and moves to an excited state. When the electron subsequently moves to a lower energy level a photon is emitted. The reason that discrete lines are observed, and not a continuous spectrum, is because the different energy level in the atom are quantized and have specific values. Finally, the energy that moves the electron to an excited state may be **radiant, heat, or electrical**. In your earlier investigation radiant energy led to the excitation. In this investigation you will consider examples of thermal (heat) and electrical excitations.

What are everyday examples of light being emitted following electrical or thermal excitation? As you will see in this investigation, technological applications like sodium,

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neon, or mercury vapor lamps are based on electrical excitations and the brilliant colors of fireworks (kaboom!) depend on thermal excitations. Phenomena such as these are explained by extending our conceptual models from last lab (for hydrogen) to describe polyatomic atoms and ions.

	Activity	Comment	Estimated time
1)	Computer Simulation: Discharge Lamps	Worksheet.	About 60 minutes.
2)	Flame Tests	Completed in lab.	About 30 minutes.

Total time ~1.5 hours

All in-lab activities may be discussed with classmates and/or completed in a small group. The teaching assistant will help manage your time.

Part 1) Computer Simulation – Neon Lights & Discharge Lamps

After this computer simulation you should be able to 1) explain how discharge lamps function, 2) discuss the emission of photons from these lamps in terms of an atomic model, like the Bohr model, 3) compare and contrast the emission of photons from different lamps.

There are several variables you can manipulate within the simulation:

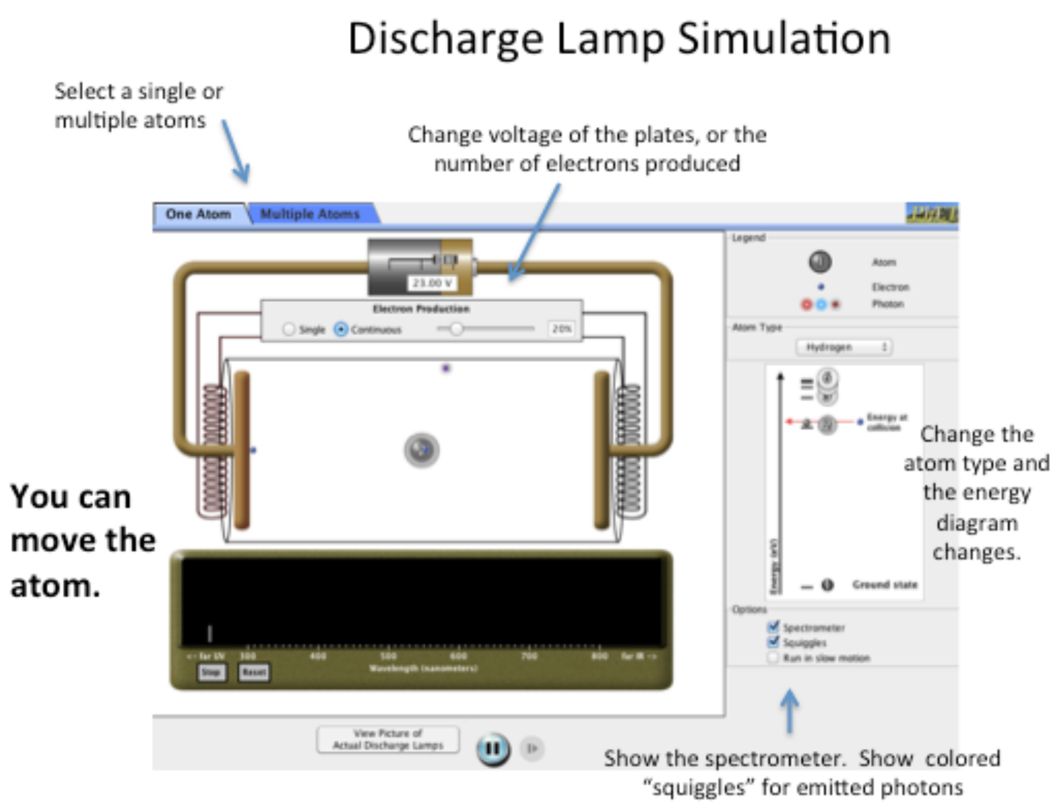
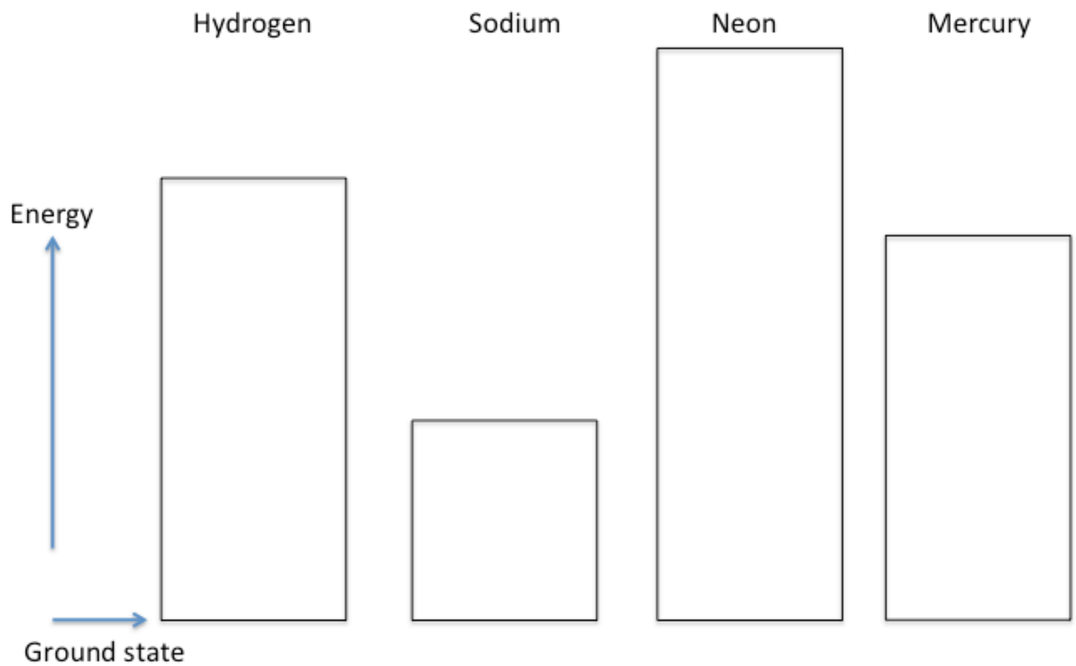


Figure 1. Overview of simulation options.

To begin your investigation sketch the electronic energy level diagram for the different atoms. To see the electronic energy levels click on **"Atom Type"** and select the desired atom.

Sketch the electronic energy levels for each atom in the appropriate box:



What is the electron configuration for each atom in its ground state?

Hydrogen: Sodium:

Neon: Mercury:

What are allowed quantum numbers (n, l, m_l, and m_s) for the most energetic electron in the ground state? (Sodium is done as an example).

Hydrogen: Sodium: n=3, l=0, m_l =0 m_s=+1/2 or -1/2

Neon: Mercury:

TO GET STARTED: By having electrons strike the atom you can cause it to emit photons, and the energy of the emitted photons is recorded by the **spectrometer**. The electron production can be **single** or **continuous** and the voltage may be adjusted (see the top of the screen, as shown in figure 1). You must turn on the spectrometer to record the emitted photons (right side of the screen, figure 1). In the **"Atom Type"** pull-down menu you can configure (move) the energy levels and also add energy levels, or choose a particular element (like neon).

Start producing electrons and use the simulation to gather information and answer the following questions:

Select the ONE ATOM tab.

	STATEMENT	True or False?
1	In Bohr's model of the hydrogen atom, as the principal quantum number (n) increases, the energy-levels follow a clear pattern and converge. An identical pattern is found for Hg, Ne, and Na.	
2	The energy **emitted** from a discharge lamp is quantized. (Hint: look at the spectrometer).	
3	Photons are emitted as electrons move to a **higher** energy level.	
4	If the spacing between two electronic energy levels in atom A is larger than in atom B, then the **wavelength** of the light emitted by atom B will be longer. (You may want to use the configurable atom to answer this question).	
5	If the spacing between two electronic energy levels in atom A is smaller than in atom B, then **fewer photons** will be emitted by atom B. (You may want to use the configurable atom to answer this question).	
6	Electrons are destroyed when they strike an atom, causing an excited state.	

Can an emission spectrum be produced from a single **neon atom**? (The answer is "yes").
The emission spectra for single atoms of hydrogen, mercury, or sodium occur "automatically" in this simulation. This is not the case for neon. Try to manipulate the different variables (voltage, number of electrons produced, placement of the Ne atom, etc.) and figure out how to obtain the Ne emission spectrum.

Why is it more difficult to cause photons to be emitted from neon?

Select the MULTIPLE ATOM tab.

	STATEMENT	True or False?
1	In a discharge lamp the energy that moves the electron to a higher energy level (an excited state) must be electrical.	
2	The only way to emit IR photons is by having empty electronic energy levels very close to the ground state	
3	Neutral atoms of different elements have different number of electrons. As the number of electrons increases, so too does the **number of spectral lines** in the visible region.	
4	For a collection of many atoms, some are in an excited stated and others are in the ground state. At *any* point in time most of the atoms have electrons in the ground state.	

Ionization Energy

In this simulation you have added energy to atoms in their gaseous state causing electrons to move to excited states. What if even more energy was added to an atom in its gaseous state? Would it be possible to completely remove an electron and form an ion? YES!

The **ionization energy** of an atom or ions is the amount of energy required to remove an electron from the ground state of the isolated gaseous atom or ion. For sodium, the first ionization energy is the energy required for the process:

$$Na\,(g) \rightarrow Na^{+}\,(g) + e^{-}$$

What is the electron configuration for each <u>ion</u> after an electron was removed?

Hydrogen: N/A

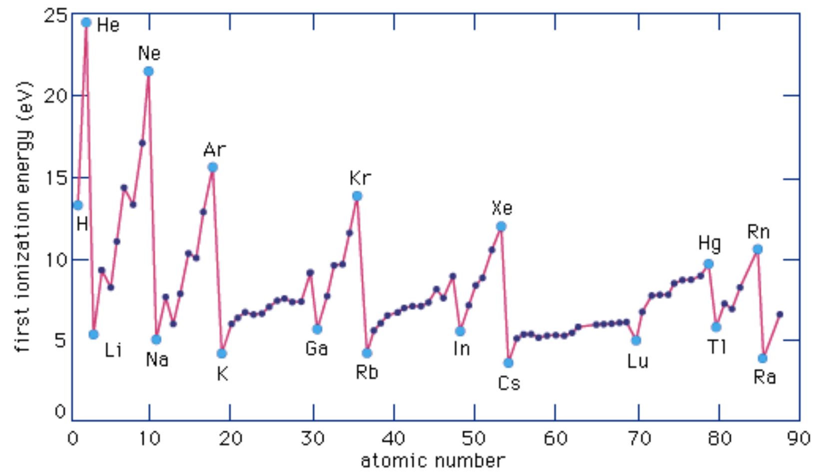
Sodium:

Neon:

Mercury:

Consider the first ionization energies for different atoms shown in the figure.

Based on these data, how is ionization energy related to the electronic energy level diagrams shown in the simulation?



Do you predict the spacing of the electronic energy levels will be the same or different for Li, Na, and K (moving down a column in the periodic table)?

How do you predict the spacing of the electronic energy levels change moving from Li to O to Ne (moving across a row in the periodic table)?

The spacing of the electronic energy levels for Na and Ne are very different. Explain why. (Hint: consider the effective nuclear charge).

Scientific & Technological Advancements

Scientific & technological advancements are often inter-dependent. For example, cathode rays were generated in tubes similar to discharge lamps and investigation of these rays led to the discovery of the electron by J.J. Thompson (as discussed in chapter 2). A similar tube was used to investigate the photoelectric effect by Philipp Lenard that led to Einstein's interpretation of light as a particle (or "photon", discussed in chapter 6). These ideas (electrons and photons) were combined in Bohr's atomic model and description of the emission of photons. Subsequently, these ideas have been used to develop new technologies, such as sodium, mercury vapor, and neon lamps. In short, this is an example of technology fueling scientific advances, which then produce technological gains.

Sodium, mercury vapor, and neon discharge lamps are commonly used in our modern society. Use your knowledge of discharge lamps and the computer simulation to answer the following questions:

One of these lamps has a great deal of heat being emitted along with visible light. **Which lamp will be the hottest?** (Hint, look at the infrared region).

The color of light we observe from a discharge lamp is a combination of all of the individual emission lines. If the energy of the photons span the entire visible region the color will appear "white". This combining of colors is the opposite of what occurs in a spectroscope.
Which lamp emits <u>yellow light</u> (and is used in street lamps)?

Which lamp emits <u>white light</u> (and is used in warehouses, sports arenas, and factories)?

Part 2) Flame Tests of Metals

When energy is added to atoms or ions of a particular element, electrons can absorb the energy and move to a higher energy level. When the electrons of these “excited” atoms or ions return to their normal ground state, energy is emitted.

As you have observed experimentally the emission spectra for hydrogen and helium are different from each other. Also, the energy level diagrams may be different for different elements and this means their emission spectra may be different. When you look at these excited atoms or ions with the naked eye you see only a single color that is the “sum” of all the individual colors emitted. In this activity you will observe this phenomena for different metal salts that have been excited by heating in a flame.

Materials Required

Equipment	**Common Equipment**	**Chemicals**
Burner	Wooden splints (pre-soaked)	Salts of various metals, such as sodium, potassium, calcium, barium, strontium, lithium, and copper.

Caution

Goggles must be worn throughout the experiment. Do not touch solutions with your bare hands. Use caution with the burner.

Waste Disposal

Metal salts go into the inorganic waste.

Procedure:

1. Light and adjust your Bunsen burner; ask for assistance if you are unsure how to use the burner.

2. A test solution may be provided for each metal. If not, simply add a small amount of the provided solid salt (about ½ of a gram) to a small amount of distilled water (about 10-20 mL) to prepare a reasonably concentrated solution. Calculating the exact concentration is NOT necessary.

3. To do a flame test with each metal salt, get a film of the solution on a wooden splint and bring it into the hottest part of the flame. To avoid contamination, use a different splint for each test solution. If this produces poor color then try the edge of the burner flame. Repeat the test as often as necessary to see the flame test color. Be sure not to over-heat the splint.

4. In your notebook record the **name** of each compound and the **overall color** of each when it is put in the flame.

Questions

1. List the elements tested in the flame test in order of increasing energy of the light emitted (based on the general color of the flame).

   Is the emitted color of light a periodic trend? Is the trend (or lack of trend) consistent with what you observed in the discharge lamp simulation?

2. In your own words, explain what is happening to the electron during the flame test. Use the following terms: Energy, ground state, excited state, wavelength, frequency, energy level & photon.

3. Could flame tests be useful in determining identities of metals in a mixture of two or more salts? Explain your reasoning.

4. Many fireworks contain metal salts like the ones you tested in this activity. Describe the chemistry that produces the colors.

hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 * *	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
**Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]