

# Quantum Leap<sup>1</sup>

**A Mechatronics Demonstration Project**

**by**

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<sup>1</sup> This work was supported by the National Science Foundation under a RET Site Grant 0227479.

## Abstract

Concepts in modern physics are challenging to teach because students have to grasp models of microscopic and invisible particles. This project offers a visual demonstration of several key ideas in modern physics: the Bohr model of the atom; quantization of energy in photons; atomic spectra and the relationship between energy and frequency of light. “Quantum Leap” calls for students’ active participation with a hands-on approach. Hands-on activities are supported by contemporary literature examining the most effective ways to engage students in science. Quantum Leap allows students to test their predictions for values of energy and frequency and for emission and absorption spectra through a hands-on mechatronic device.

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## **1. Curriculum Standards Correlation**

This project addresses concepts in modern physics and quantum theory. It can be used to illustrate the Bohr model of the atom and the concept of quantized energy, and provides a visual representation of absorption and emission spectra. It correlates to the following New York State Physical Setting/Physics and Core Curriculum Standards:

### **STANDARD 1—Analysis, Inquiry, and Design. Mathematical Analysis**

Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

### **STANDARD 6—Interconnectedness: Common Themes**

Students will understand the relationships and common themes that connect mathematics, science, and technology and apply the themes to these and other areas of learning.

### **STANDARD 7—Interdisciplinary Problem Solving**

Students will apply the knowledge and thinking skills of mathematics, science, and technology to address real-life problems and make informed decisions.

### **STANDARD 4—The Physical Setting**

Students will understand and apply scientific concepts, principles, and theories pertaining to the physical setting and living environment and recognize the historical development of ideas in science.

In particular, Quantum Leap addresses the following key ideas from Standard 4:

#### **Key Idea 4 - Energy exists in many forms, and when these forms change energy is conserved.**

Students will:

- 4.1 Observe and describe transmission of various forms of energy.
- 4.3 Explain variations in wavelength and frequency in terms of the source of the vibrations that produce them, e.g., molecules, electrons, and nuclear particles.

#### **Key Idea 5 - Energy and matter interact through forces that result in changes in motion.**

Students will:

- 5.3: Compare energy relationships within an atom's nucleus to those outside the nucleus
  - 5.3i – interpret energy level diagrams
  - 5.3ii – correlate spectral lines with an energy-level diagram

The experiment also addresses the following performance indicators:

#### **Performance Indicators:**

- 5.3a States of matter and energy are restricted to discrete values (quantized).
- 5.3c On the atomic level, energy is emitted or absorbed in discrete packets called photons.
- 5.3d The energy of a photon is proportional to its frequency.

5.3e On the atomic level, energy and matter exhibit the characteristics of both waves and particles.

5.3f Among other things, mass-energy and charge are conserved at all levels (from subnuclear to cosmic).

The project also supports the following National Education Technology Standards (NETS) as outlined by the International Society for Technology Education (ISTE):

**Standard Area 3: TEACHING, LEARNING, AND THE CURRICULUM.**

Teachers implement curriculum plans that include methods and strategies for applying technology to maximize student learning.

Teachers will:

- A. Facilitate technology-enhanced experiences that address content standards and student technology standards.
- B. Use technology to support learner-centered strategies that address the diverse needs of students.
- C. Apply technology to develop students' higher order skills and creativity.
- D. Manage student-learning activities in a technology-enhanced environment.

## **2. Introduction**

You are probably reading this paper in a library or a classroom, and if you take a look up, chances are that you will see a fluorescent light. Have you ever wondered how fluorescent lights work? Did you know that there is no filament running through the long bulb, and it is filled only with gas? The Bohr model of the atom provides an explanation to this mystery, as well as to a range of other phenomena, from black light posters to lasers. Bohr's model provides an atomic explanation to the concept that all forms of energy are packaged in discrete amounts - called quanta. This idea paved the road to the exciting field of quantum mechanics.<sup>1</sup> It also reaffirmed Einstein's theory that light itself is made of tiny bundles of energy, and these bundles – or quanta – are now known as photons.<sup>2</sup>

When studying this topic, it is relatively difficult for students to visualize the Bohr Model's processes and interaction between energy and light, in particular the emission (or absorption) of light which is the result of electrons moving between different energy levels of the atom. Thus, this project, named Quantum Leap, offers a hands-on approach which will facilitate students' conceptual understanding. Before experimenting with Quantum Leap, it is suggested that students make predictions for a given situation, what the outcome will be for the spectra, the

amount of energy, and the frequency of the photon. Next, students would use Quantum Leap to simulate the given situation. Quantum Leap is built upon mechatronics technology (the integration of mechanical, electrical, control interface, and computer programming) and provides an interesting and high-tech interface for student use. By conducting this experiment, students would be encouraged to visualize a given situation, compare its outcome to their predictions, and be further engaged in the learning process.

### **3. Background**

#### **3.1 Theory**

##### **3.1.A. Early Atomic Models**

The idea that distinct elements make up the world around us can be traced back to the ancient Greeks and Romans but the structure of atoms was not understood until relatively recent times. The model of the atom we know today has roots that reach back over many years beginning in the early 19<sup>th</sup> century. The current model evolved through the discoveries and models put forth by scientists including Dalton, Thomson, Rutherford and Bohr. Dalton first proposed the atom as a tiny indestructible, uniform sphere that comprised all matter. Thomson improved this model when he used his cathode-ray tube experiment to detect charged particles inside the atom. He proposed the idea that the negatively charged “corpuscles” were imbedded into the positive atom much like chocolate chips in a cookie.<sup>3</sup> Ernest Rutherford’s gold foil experiment revolutionized thought on the atom when he detected the relatively small, hard and positively charged nucleus in the center of the atom. Rutherford’s model described the atom as a miniature solar system where electrons orbit the nucleus. According to this planetary model, electrons would be changing direction in order to orbit the nucleus. However, a change in direction indicates acceleration and accelerating charges radiate energy. This loss of energy would be continuous as the electron moved around the nucleus causing a decrease in kinetic energy and eventually would result in the electron spiraling into a collision with the nucleus. Further, during this period in history, it was known that certain definite frequencies of light were emitted corresponding to excited atoms of certain elements. These bright-line spectra are still used to identify elements today. According to Rutherford’s model, light would be emitted continuously instead of discretely, which was in direct conflict with known atomic behavior. Rutherford knew these were the implications and failures of his model, but was unable to put forth a solution.<sup>4</sup>

### 3.1.B. The Bohr Model of the Atom

Roughly two years after Rutherford's experiment, Neils Bohr offered an explanation to rectify Rutherford's model. Bohr proposed a model of the atom that allowed electrons to maintain specific energies and still orbit the atom. Bohr studied the hydrogen atom to develop his theory because it has the lowest atomic mass and the simplest bright-line spectrum. Bohr's model explained the particular emission of colors from excited hydrogen atoms and why the electron does not collide with the nucleus. Bohr's proposal was surprising and revolutionary. He suggested that electrons do not radiate energy even though they are accelerating as they change direction around the nucleus. He hypothesized that electrons orbiting an atom maintain the same energy within a given "energy level." Each energy level has a fixed radius and may only be reached by emitting or absorbing a discrete amount of energy. The lowest energy level is closest to the nucleus and is called the ground state. Electrons occupying energy levels above the ground state are considered to be in an excited state. These energy levels proposed by Bohr came to be known as the Bohr model of the atom and showed distinct energies allowable for the hydrogen atom. (See figure 1.)

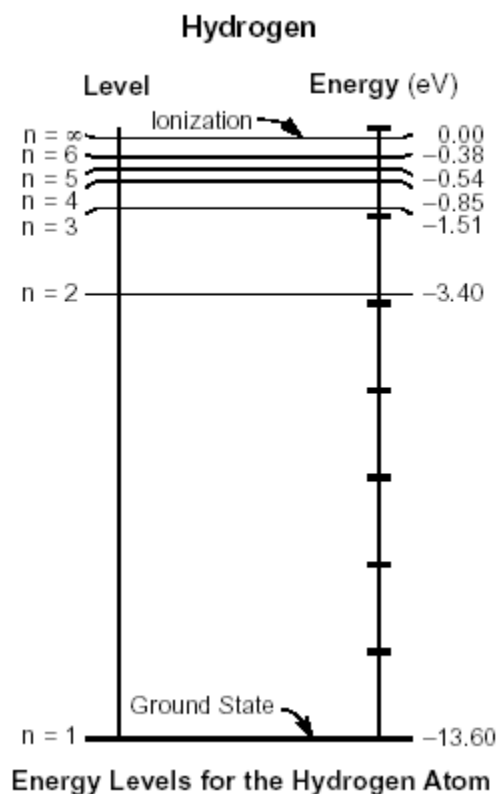


Figure 1.<sup>5</sup>

### 3.1.C. Quantization of Energy

When Bohr was trying to use Rutherford's findings to determine a better model of the atom's structure, he looked towards Einstein's theory of light. Einstein's proposed theory explained light was made up of discrete packets of energy that had the ability to act like particles. He called these packets of energy "photons." This was a revolutionary idea not yet widely supported, but it worked very well with Bohr's ideas. Bohr said that since light from atoms only was emitted at certain frequencies corresponding to certain colors, that light must relate to certain energies as described by Einstein's theory:

$$E = hf$$

where  $E$  is the energy of the photon emitted or absorbed,  $h$  is Planck's constant and  $f$  is the frequency of the light. The energy emitted or absorbed when an atomic electron changes energies is equal to the energy of a photon that can be calculated by finding the difference between energy levels:

$$E_{\text{photon}} = E_{\text{initial}} - E_{\text{final}}$$

where  $E_{\text{initial}}$  is the original energy level and  $E_{\text{final}}$  is the energy level after the electron jump. These energies emitted or absorbed when an electron changes levels correspond to the light given off or absorbed when an electron jumps down or up a level, respectively.<sup>6</sup>

### 3.1.D. Absorption and Emission Spectra

A phenomenon long recognized by scientists was the emission and absorption of light by gaseous elements. The heated gas of an element will emit a color or colors characteristic of that element resulting in bright colored lines when viewed through a spectroscope. Similarly, cool gas will absorb certain colors from white light that is incident upon it which results in dark lines in the continuous spectrum when observed through a spectroscope.

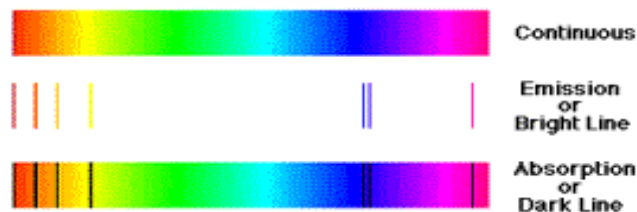


Figure 2.<sup>7</sup> Examples of emission and absorption spectra

The Bohr model of the atom explains these phenomena through the quantization of energy. The photons emitted from the heated – excited – gaseous atoms correspond to certain colors and the



cool – non-excited- atoms will absorb only certain color photons that correspond to the specific energy levels of the atom.

### **3.1.E. Limitations of the Bohr Model**

Bohr developed his model using the hydrogen atom because it was the simplest atomic spectra known. However, Bohr's model becomes difficult to extend to other elements that have more than one electron. In addition, Bohr assumed only circular orbits, which we now know do not align with the specific elliptical orbits described by quantum theory. Despite the shortcomings of the Bohr model, it was his revolutionary thinking that paved the way for further atomic model study and development.<sup>8</sup>

## **3.2 Project Idea**

### **3.2.A. The Need For More Hands-on Activities**

The New York State physics curriculum includes roughly six broad areas of physics: kinematics; dynamics; energy; electricity and magnetism; waves and light; and modern physics. For the first five areas mentioned here, there is a plethora of demonstrations, hands-on activities and laboratories readily available for teachers to share with one another and implement in the classroom. However, through the personal experience of the authors of this paper and their colleagues, it has been noted that subject of modern physics often lacks that same student involvement and teachers often resort to charts and diagrams to explain concepts that already seem abstract to students. It was for this reason that Quantum Leap was developed.

### **3.2.B. Classroom Goal**

When teaching students about absorption and emission spectra, teachers may show charts of these spectra or even burn elements to have students observe the colors of light emitted while using spectrosopes. While the latter method engages students, through the personal experience of the authors of this paper and their colleagues, it has been observed that students often have difficulty seeing the spectra because the flame lasts for a brief period of time and also because students may not have much experience using a spectroscop. Therefore, the combined lack of hands-on activities in modern physics and difficulty of successfully using the existing demonstration prompted the idea of a tool that would be interactive and interesting to students,

yet display fundamentals of the Bohr model and absorption and emission spectra. Quantum Leap allows students to move an “electron;” see the color of light that would be emitted or absorbed; and note the amount of energy change that occurs.

## **4. Components**

### **4.1 Equipment List**

The list below covers the materials used to build the entire project, including mechanical, electrical and non-electrical components. The following sections will describe the major components in greater detail.

- Board of Education project board from Parallax Inc.
- Basic Stamp 2 Integrated Circuit from Parallax Inc.
- 7 Photoresistors
- Servo Motor
- 7 Resistors for LEDs
- 7 Resistors for photoresistors
- 2 Fiber Optic lighting
- 2 plates of 3/8” Plexiglass squares, 16” x 16”
- 2 3/8” Plexiglass squares, 8” x 8”
- 6 1” standoffs
- 16 1” long screws
- 2 1/2” metal balls
- 2 bread boards
- 7 LEDs (Red, Yellow, Green, Red-Super Bright, Blue, UV)

### **4.2 Board of Education with Basic Stamp 2**

The BASIC Stamp 2 (BS2) module is a very popular integrated circuit for learning purposes. This module normally has 2K bytes of program space and 16 Input/Output pins. It can be programmed to perform different and various applications with a simple, user-friendly programming language which is called “PBasic.” The BS2 is designed for Serial PC interface and also provides enhanced debug features, which make the learning process more efficient. The BS2 is mounted on the Board of Education (BOE) to constitute the microcontroller for this project. A microcontroller is basically a mini-computer (but without human interface such as keyboard and mouse) with a small amount of memory that can hold and execute PBasic programs. The BOE also serves as a breadboard for circuitry and comes with a DB9 connector

for (serial) communication with the BS2. The BOE provides power to the project – it is driven by a 6-14V direct current (VDC), while an integrated voltage regulator provides a steady 5VDC output to the BS2 integrated circuit. Figure 3 below shows the BOE and BS2:

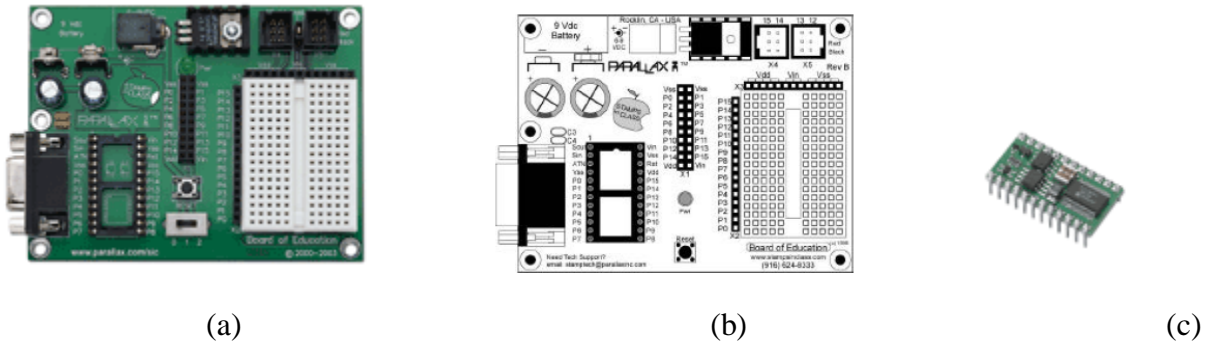


Figure 3: Board of Education (a), Board of Education schematic (b), and Basic Stamp 2 (c).<sup>9</sup>

### 4.3 Photoresistors

A photoresistor is a variable resistor that changes its value according to the intensity of light. Under dark conditions, its resistance would be very high (ideally, in the absence of light conductivity should be zero but practically the resistance is about few mega-ohms), but when exposed to light its resistance would drop to a very low value (in the range of few hundred ohms). Photoresistors are usually made of cadmium sulfide and are very sensitive to light, and thus can be used to detect lighting conditions. When the lighting conditions change, the voltage across the resistor changes and the current flowing through the resistor changes.<sup>10</sup> Figure 4 shows 2 common photoresistors (a) and the common schematic representation (b). The light arrow indicates a variable resistance, and the dark arrow indicates that the incident light triggers the change in the resistance:



Figure 4: Photoresistors (a), and Schematic of photoresistor (b).

#### 4.4 LED

An LED is a Light Emitting Diode. A diode is a semiconductor device that allows the flow of current only in one direction (similar to traffic moving in a one-way street). Diodes are used for various applications, including the conversion of alternating current to direct current.<sup>11</sup> When current flows in the desired (forward) direction through an LED, the diode gives off light. LEDs can give off light of different colors, from infrared all to ultra violet. This project uses LEDs of different colors, and since each LED requires different voltage and current, different resistors were used for each LED (please see circuit diagram for the values of each resistor). The figure below shows an LED and a schematic of an LED:



Figure 5: LED (a), and Schematic of LED (b).

#### 4.5 Transistor

Transistors are semiconductor devices that act as electrically controlled switches and as current amplifiers. There are three types of transistors: Bipolar Junction Transistors (BJT), Junction Field Effect Transistors (JFET), and Metal Oxide Semiconductor FET (MOSFET). The transistors can be either NPN or PNP, depending on the internal arrangement of the semiconductor materials and the doping.<sup>12</sup> The transistors have 3 legs which are labeled as Base, Emitter, and Collector. In this project, the BJT NPN transistor was used. The base is used to control the flow of current from the collector to the emitter in the following way: if the potential at the base is higher than the potential at the emitter, than the switch is on and current flows, otherwise the switch is off and current cannot flow. The transistors were used in this project as switches to control the LEDs: When a user input requires a specific LED to light, the BS2 would set the appropriate pin high, which is connected to the transistor, which in turn would allow the current to flow through the designated LED. Figure 6 shows typical transistors and a schematic of a transistor:



Figure 6: Transistor (a), and Schematic of Transistor (b).

#### 4.6 Servo Motor

A motor is a mechanism that converts electrical energy to mechanical energy (a generator does the reverse process, i.e. converts mechanical into electrical energy). A servo motor has various advantages over a regular motor. The major characteristics of a servo motor are speed and direction control. By enhancing a regular motor with a gearbox, potentiometer, control circuitry and a control input, the microcontroller can send different commands to the motor and change its speed and direction according to desired conditions set by the user. In this project, the servo motor is calibrated to move a needle to point to specific energy level on an energy scale. This action is achieved by the BS2 sending the signal with the PULSOUT command. This command can control the angle of rotation of the servomotor.



Figure 7: Servomotor (a), and Schematic of Servomotor (b).

## 5. Project Design

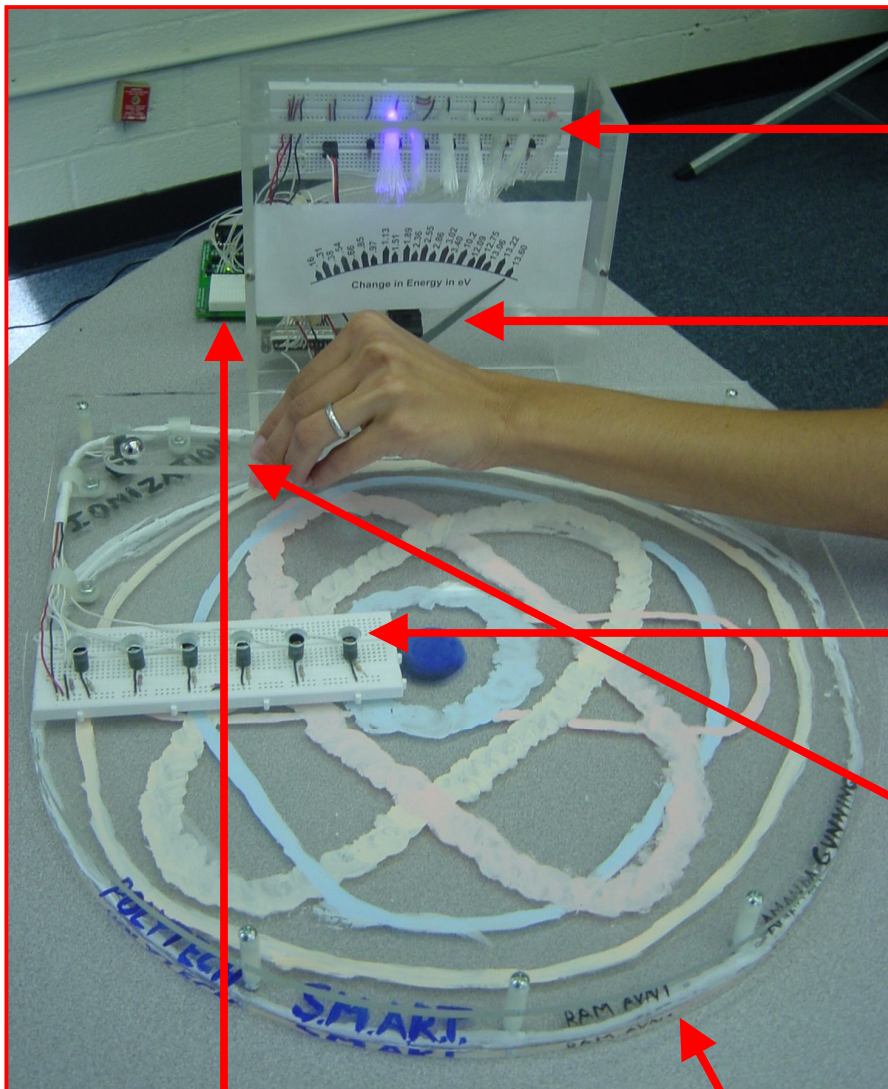
### 5.1 Operation

Quantum Leap was created to allow a student to freely choose which energy level transition an electron in a hydrogen atom will make (based on the Bohr model of the atom) or to illustrate a

transition as specified by a given physics problem. The student or teacher will move a small metal sphere that represents the electron by using a clear wand to the initial energy level and then to a different level or to a point representing ionization of the electron. The levels and ionization point are represented by holes drilled into the user interface where the metal ball will easily sit. Once an initial level is chosen and the ball has been placed there for a moment, the user may then move the ball to the next desired position. Once this transition is made, a light display will show either the color of light emitted or the spectrum with the absorbed color missing. At the same time, the servomotor will move a needle that will point to the corresponding energy change of this jump and frequency range. At this time, the user may chose to reset the Quantum Leap or make a second energy level transition.

## **5.2 Quantum Leap Setup**

Quantum Leap is powered by an AC outlet through a DC adapter, which is connected to the BoE. Photoresistors detect the placement of the “electron” by the user. Once the initial and final placements of the electron are detected by the photoresistors, the program running inside BS2 processes these values at the pins connected to the photoresistors as either high or low. The program then sets the appropriate pins controlling the LEDs high or low, which then light the fiber optics. At this time, the program also directs the servomotor how much to turn in order to land the needle upon the proper energy and frequency values. (See Figure 7.)



LEDs with short fiber optics attached

Servomotor with needle attached

Photoresistors inside heat shrink tubing situated under holes in plexiglass

Plexiglass wand and "electron" (metal ball)

Figure 8. Quantum Leap Device

Two layers of plexiglass separated by plastic standoffs attached together with metal screws

BOE with BS2

## 6. Project Design

### 6.1 Circuit Design

In Quantum Leap, seven photoresistors are connected to Vdd, each through a 100 kΩ resistor. The presence of this high resistance protects the microcontroller pin. The other leg of the photoresistor connects to a pin on the microcontroller and Vss (ground). When light is detected

by the photoresistor, current flows and the pin turns low. Conversely, when there is no light reaching the resistor, the resistance gets infinitely high and no current flows to the pin, creating a potential difference, and turning the pin high.

The LEDs are each connected to Vdd and then to an appropriate resistor, which protects both the pin of the microcontroller and the LED from receiving too much current. Resistors used vary based on the specifications of each LED. The LED and resistor are connected to the collector pin of an NPN-transistor. The base of the transistor is connected to a pin of the microcontroller and the emitter pin of the transistor is connected to ground. This transistor acts as a switch. When the pin is turned low, a potential difference is detected and current flows through the transistor turning on the LED. When the pin is set low, the LED remains dark. To offer further protection to the delicate pin of the microcontroller, a 470  $\Omega$  resistor is placed between it and the base pin of the transistor. (See figure 9.)



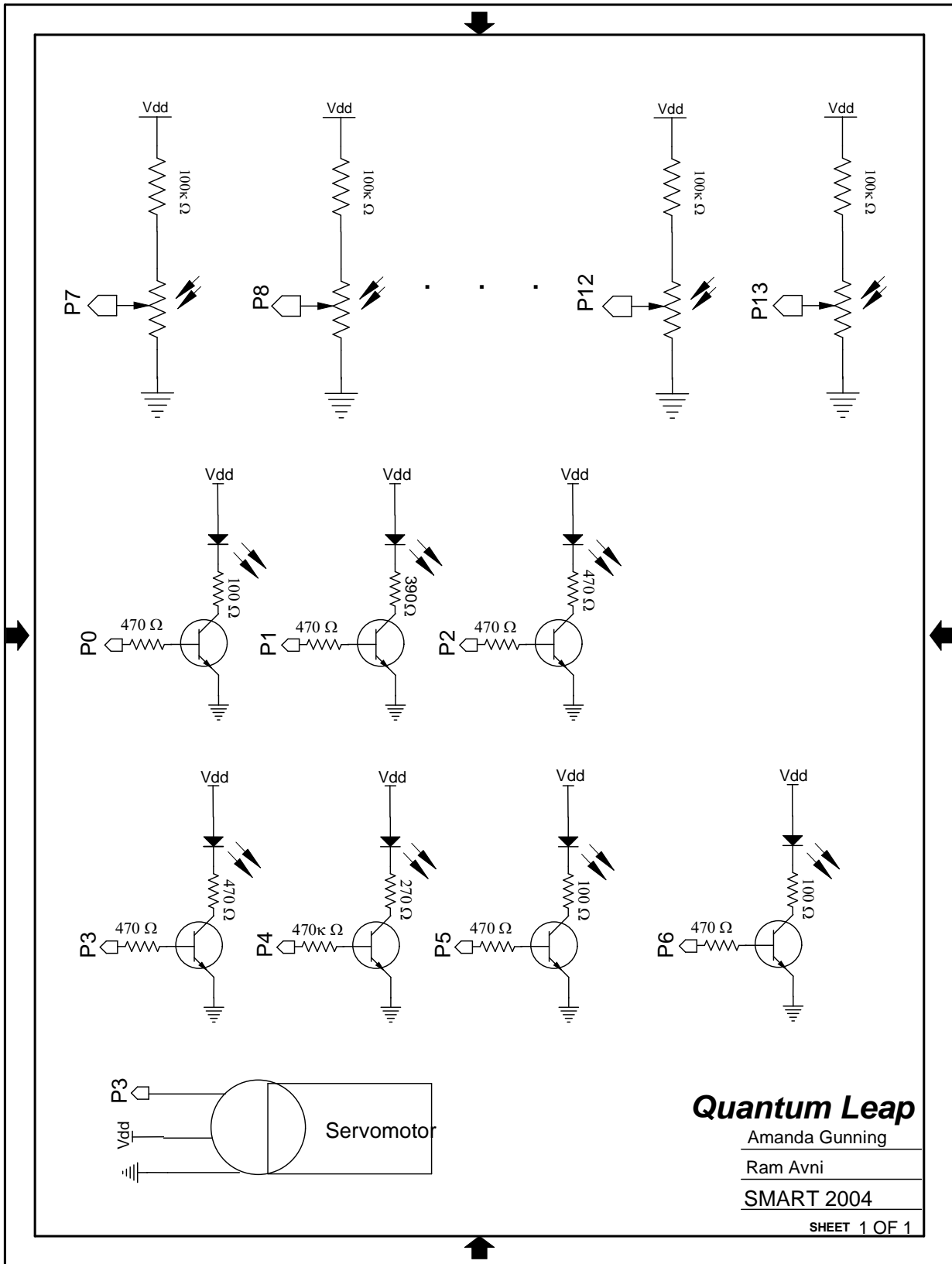


Figure 9

## **6.2 Program Logic**

### **6.2.A Electron Location Detection**

The program uses seven photoresistors that represent the various possible energy shells an electron may occupy in a hydrogen atom. Each photoresistor is connected to a specific pin on the BS2. Initially, all photoresistors are set low. When a user places an electron in a specific energy level, the photoresistor resistance increases and causes the appropriate pin to go high. The first module of the program loops until it detects that an electron was placed in a particular level, and stores this level number in memory.

The second module functions in a similar way – it waits until the electron is placed in a second location and stores the level number in memory. The second module achieves two additional objectives: 1) it also compares the first and second orbit numbers and ensures that the program continues only when the electron was placed in a different orbit. 2) it allows the program to continue smoothly for another user, without a need to reset the microcontroller. In this manner, several users can simulate “quantum leaps” continuously, one after the other, and observe the results of each electron move.

### **6.2.B Calculating Spectra Lines**

This module displays the output of the program. The first thing that this module does is to find out, based on the photoresistors’ output, whether an absorption or emission spectra is required. Based on this information, displays the appropriate spectra by turning on and off the corresponding colors. Control of the display is achieved by connecting seven LEDs to seven pins on the BS2, and setting the pins high or low as required.

### **6.2.C Energy Level Indication**

The last module of the program is responsible for displaying the correct change in energy. This task is achieved through the connection of a needle to the servo motor, and rotating the servo by a set amount based on the electron’s change in position. The needle would then point to an energy scale, indicating the change in energy and the frequency of the light emitted or absorbed.

## **7. Results**

Quantum Leap successfully shows one or several consecutive electron energy level transitions when used properly with the plexiglass wand. False readings are often generated when a user uses his or her hand to move the metal ball because photoresistors are unintentionally triggered from the hand's shadow. Also, if one leans over the device or passes one's hand over the photoresistors it is possible to mistakenly trigger the photoresistor. This glitch was addressed by creating the wand for moving the electron, which is effective in limiting this problem, and by putting the heat-shrink tubing around each photoresistor, which also helps. Overall, Quantum Leap is deemed successful by its developers.

## **8. Conclusions**

The goal of the authors of the developers of Quantum Leap was to create a device that could successfully model bright-line emission and absorption spectra in an engaging way for students. Students will be able to first calculate on their own: the expected energy gain or loss by the electron; frequency of the emitted or absorbed photon; and based on the New York State Board of Regents Reference Table, the color of the light of that frequency. Students may then check their answers using Quantum Leap. Of course, students and teachers may also simply move the electron to different energy states and observe the results. Based on its operational success and the positive reactions from other science teachers and professionals in the field of science and education, the developers of Quantum Leap believe the device will successfully engage students in the classroom and demonstrate concepts in modern physics.

## **9. Suggested Activities**

### **9.1 Projects**

- A. Enhance the "Quantum Leap" so that a user can enter the initial and final energy levels in a computer or other user interface, and the device will move the electron automatically.
- B. Write a computer program that takes a specific color as input, and shows the motion of the electron as output.
- C. Write a computer program that displays the emission and absorption spectra on the computer screen in addition to the LED display.

## 9.2 Lesson Plans/Class Activities

The following activities are suggested in order to gain students' conceptual understanding before drilling into mathematical calculations and Regents review questions. These activities can be modified by teachers as they find fit, integrate them into existing lesson plans, or add them as extension. In the following questions, students should refer to the Bohr Model of the hydrogen atom:

### 9.2.A. Fill in the blanks:

The Bohr model of the hydrogen atom supports the idea that all forms of \_\_\_\_\_ are quantized. A quantum is a \_\_\_\_\_ amount. According to Einstein, light itself is made of tiny bundles of energy, and these bundles – or quanta – are known as \_\_\_\_\_.

The most stable condition of an electron is called the \_\_\_\_\_ state. In order to move outwards, away from the nucleus, an electron has to \_\_\_\_\_ energy. Each energy level above the ground state is called an \_\_\_\_\_ state, because the electron had to be “shaken up” in order to leave its most cozy, stable state.

Therefore, when an electron moves to a higher energy level (further from the ground state), we would expect to see an \_\_\_\_\_ spectra. In typical absorption spectra, all the frequencies, or colors, would be \_\_\_\_\_, and only one frequency or color would be \_\_\_\_\_.

Ground  
Absorption  
Fixed

Photons  
Missing  
Energy

Absorb  
Excited  
Present

### 9.2.B. Answer the Following Questions

The following questions can be used as activities for both small groups and individual work. Each group may use the “quantum Leap” project to test their predictions or to visualize a given situation:

- 1) When an electron moves from  $n = 4$  to  $n = 2$ , a green line is shown. Is it absorption or emission spectra? Was light energy absorbed or released?
- 2) Predict whether you would see absorption or emission spectra when an electron moves from  $n = 2$  to  $n = 4$ . Can you predict which colors would be present and which colors missing? Discuss your prediction with your partner and draw your results.
- 3) Refer to the full spectrum diagram and predict the initial and final energy levels when all LEDs are lit except for the blue one. Find the energy difference that corresponds to this jump.

- 4) Suppose that now only the blue LED is lit. Would the energy difference would be less, more, or the same as in questions 3? If it is different, explain why. If it is not, what other things would be different?
- 5) When was more energy released or absorbed, when you see emission spectra with violet LED on, or when you see absorption spectra with the red LED off?
- 6) When is more energy absorbed, when an electron moves from energy level 2 to 3, or from 4 to 5?
- 7) When is more energy absorbed, when an electron moves from energy level 3 to 4, or from 5 to 6?
- 8) Based on your answers to questions 6 and 7, can you come up with a general rule about the different orbits and the energy difference?
- 9) The ground state of the atom can be visualized by a mechanical model, in which the electron is represented by a bowling ball, and the first state is represented by a hole in the ground. When the bowling ball rests in the bottom of the hole, it is in its most stable condition, and you would need to put in energy in order to move the ball outwards, to a higher level. According to this model, what does the bottom of the hole represent? What aspects are not addressed by this model? Discuss with your partner various ways to modify this model and draw it. Show your model to an instructor and explain your modifications.

## 10. Project Cost Analysis

Quantity	Item	Price
2	3/8" Plexiglass squares, 16" x 16", cut	
2	3/8" Plexiglass squares, 8" x 8"	\$66
3	1/4" Plexiglass rectangles, 8" x 3"	*
6	1" standoffs	\$5.70
14	1/2" long screws	\$3.54
7	Photoresistors	\$13.65
2	1/2 " metal balls	*
1	Servomotor	\$12
2	bread boards	**
100 ft.	Fiber Optic lighting	\$13
	Basic Stamp 2	\$49
	Board of Education	\$65
7	LEDs	\$8.70
21	Resistors	**
	<b>TOTAL:</b>	<b>\$236.59</b>
		+ gratis materials

\* Provided gratis by Alessandro Betti and the Polytechnic University machine shop

\*\* Provided gratis by the SMART program

## 11. Acknowledgements

We would like to thank Project Director Professor Vikram Kapila for his direction and inspiration; with his strong leadership, the program had direction and a sense of urgency. He instilled in us a drive to excel, learn and think creatively. Project Instructor Sang-Hoon Lee earns our deep gratitude for his unending patience and expertise. He was always ready to explain a concept if we were struggling, or provide an enlightening tidbit to help us move ahead on our own. His jovial personality also made working in the lab a pleasant experience. We would also like to thank Teaching Assistant Anshuman Panda for his assistance in the lab, for pulling apart our erroneous circuits and helping us to debug. His guidance was essential to our progress in the labs and project phase. Polytechnic University student Arthur Nisonov was a helpful consultant for us during the project development phase. His ideas and feedback helped fine tune our hardware and code. We would also like to thank Alessandro Betti for his patience, timely handiwork and materials.

Finally, we would like to thank Parallax, Inc. for donating a “Homework Board,” a “StampWorks” kit and various materials to each teacher involved in the project and Polytechnic University and the National Science Foundation for making this program possible.

## 12. Appendix A: PBasic Program

```
' {$STAMP BS2}
' {$PBASIC 2.5}
```

```
'Quantum Leap V.11
' Amanda Gunning and Ram Avni
' SMART Project, Polytechnic University, July 2004
' Last modified: August 6, 2004 ----- 10:23PM -----
' Modified by: Niels Bohr
```

```
'-----Declarations-----
DIRS = %100000001111111 'pins 0-6 as outputs - LEDs
                'pins 7-13 as inputs - Photoresistors
                'pin 14 as output - Servomotor
```

```
'-----Variables-----
Ni VAR Nib
Nf VAR Nib
n VAR Bit   'store state of first photoresistor
m VAR Bit   'store state of second photoresistor
idx VAR Nib 'turn all LEDs on/off
color VAR Bit 'turn specific LED on/off
x VAR Byte  'allow sufficient time for servomotor
time VAR Word
range VAR Word
ORIGIN CON 1000
my_debug VAR Word
```

```
'-----Main-----

'reset the needle AND the light display
                'leave photoresistors as is
OUTS = %00000000 'turn off all display lights
FOR x = 1 TO 100 'return servo-needle to origin (left side of the scale)
    PULSOUT 14, ORIGIN
    PAUSE 10
NEXT
```

```
'DEBUGIN my_debug
'DEBUG CR, CR
'DEBUG "DEBUGIN - servo to origin - before main", CR

main:
  DEBUG "Rami is going to kill me", CR
  GOSUB get_ni_value      'get the value of ni (initial state)
  DEBUG "AFTER get_ni", CR
  DEBUG ? Ni
  DEBUG ? Nf
  GOSUB get_nf_value      'get the value of nf (final state)
  DEBUG "AFTER Nffffffffffffffffffff", CR
  DEBUG ? Ni
  DEBUG ? Nf
  GOSUB calc_spectra      'calculate the energy AND frequency

GOTO main

'-----Routines-----
'-----

get_ni_value:
  'monitor all photoresistors pins and wait until one pin changes state
  'get value of first pin that goes hi
  n = 0
  Ni = 0

  n=IN7
  IF n = 1 THEN
    Ni = 1
    RETURN
  ENDIF

  n=IN8
  IF n = 1 THEN
    Ni = 2
    RETURN
  ENDIF

  n=IN9
  IF n = 1 THEN
    Ni = 3
    RETURN
  ENDIF
```



```
n=IN10
IF n = 1 THEN
'DEBUG "inside get_Ni --> n=IN10 and Ni=4"
'DEBUG "should NEVER be here - weeuuuuuuuweuuuuuu"
'DEBUG ? Ni
'DEBUG ? Nf
'DEBUGIN my_debug

    Ni = 4
    RETURN
ENDIF

n=IN11
IF n = 1 THEN
    Ni = 5
    RETURN
ENDIF

n=IN12
IF n = 1 THEN
    Ni = 6
    RETURN
ENDIF

n=IN13
IF n = 1 THEN
    Ni = 7
    RETURN
ENDIF

GOTO get_ni_value
'-----
'-----

get_nf_value:
'monitor all LED pins and wait until next pin changes state for at least 1 sec
'get value of next pin that goes hi

'DEBUG "Entering get_nf_value: ", CR
'DEBUG ? Nf
'DEBUG ? Ni
'DEBUGIN my_debug
```

m = 0  
Nf = 0

m=IN7  
IF m = 1 THEN  
  Nf = 1  
  IF Ni = Nf THEN  
    GOTO get\_nf\_value  
  ELSE  
    RETURN  
  ENDIF  
ENDIF

m=IN8  
IF m = 1 THEN  
  Nf = 2  
  IF Ni = Nf THEN  
    GOTO get\_nf\_value  
  ELSE  
    RETURN  
  ENDIF  
ENDIF

m=IN9  
IF m = 1 THEN  
  Nf = 3  
  IF Ni = Nf THEN  
    GOTO get\_nf\_value  
  ELSE  
    RETURN  
  ENDIF  
ENDIF

m=IN10  
IF m = 1 THEN  
  Nf = 4  
  IF Ni = Nf THEN  
    GOTO get\_nf\_value  
  ELSE  
    RETURN  
  ENDIF  
ENDIF

m=IN11  
IF m = 1 THEN

```
Nf = 5
IF Ni = Nf THEN
  GOTO get_nf_value
ELSE
  RETURN
ENDIF
ENDIF
```

```
m=IN12
IF m = 1 THEN
  Nf = 6
  IF Ni = Nf THEN
    GOTO get_nf_value
  ELSE
    RETURN
  ENDIF
ENDIF
ENDIF
```

```
m=IN13
IF m = 1 THEN
  Nf = 7
  IF Ni = Nf THEN
    GOTO get_nf_value
  ELSE
    RETURN
  ENDIF
ENDIF
ENDIF
```

```
IF ((m = 0) AND (Nf=0)) THEN
  GOTO get_nf_value
ENDIF
```

```
GOTO get_nf_value
```

```
'-----
```

```
'-----START compare-----
```

```
'-----END compare-----
```

```
'-----START calc_spectra-----
```

```
calc_spectra:
```

```
'DEBUG "Entering calc_spectra", CR
```

```
'DEBUG ? Ni
'DEBUG ? Nf
'DEBUGIN my_debug
```

```
range = ORIGIN
PULSOUT 14, ORIGIN      'move needle to origin
FOR x = 1 TO 50        'return servo-needle to origin (left side of the scale)
  PULSOUT 14, ORIGIN
  PAUSE 10
NEXT
```

```
'DEBUG "calc_spectra - origin set", CR
'DEBUG ? Ni
'DEBUG ? Nf
'DEBUGIN my_debug
'DEBUG CR
```

```
'DEBUG "calc AFTER origin", CR
```

```
IF (Nf > Ni) THEN
```

```
'DEBUG " calc_spectra - IF Nf > Ni", CR
'DEBUGIN my_debug
'DEBUG CR
```

```
'DEBUG ? Ni
'DEBUG CR
'DEBUG ? Nf
'DEBUG CR
'DEBUGIN my_debug
'DEBUG CR
```

```
FOR idx = 0 TO 6      'all LEDs on
  HIGH idx
NEXT
PAUSE 500
color = 0
ELSEIF (Nf < Ni) THEN
```

```
'DEBUG "calc_spectra - ELSEIF Nf < Ni", CR
'DEBUG ? Ni
'DEBUG ? Nf
```

```
'DEBUGIN my_debug
```

```
    FOR idx = 0 TO 6      'all LEDs off for a moment
      LOW idx
    NEXT
    PAUSE 500
    color = 1
  ENDIF

  IF ( (Ni = 7 AND Nf=6) OR (Ni =6 AND Nf=7) ) THEN
    range = 940
    GOSUB move_servo
    OUT0 = color
  ELSEIF ((Ni = 7 AND Nf=5) OR (Ni = 5 AND Nf=7)) THEN
    range = 890
    GOSUB move_servo
    OUT0 = color
  ELSEIF ((Ni = 7 AND Nf=4) OR (Ni = 4 AND Nf=7)) THEN
    range = 840
    GOSUB move_servo
    OUT0 = color
  ELSEIF ((Ni = 7 AND Nf=3) OR (Ni = 3 AND Nf=7)) THEN
    range = 765
    GOSUB move_servo
    OUT0 = color
  ELSEIF ((Ni = 7 AND Nf=2) OR (Ni = 2 AND Nf=7)) THEN
    range = 650
    GOSUB move_servo
    OUT6 = color
  ELSEIF ((Ni = 7 AND Nf=1) OR (Ni = 1 AND Nf=7)) THEN
    range = 510
    GOSUB move_servo
    OUT6 = color
  ELSEIF ((Ni = 6 AND Nf=5) OR (Ni = 5 AND Nf=6)) THEN
    range = 975
    GOSUB move_servo
    OUT0 = color
  ELSEIF ((Ni = 6 AND Nf=4) OR (Ni = 4 AND Nf=6)) THEN
    range = 915
    GOSUB move_servo
    OUT0 = color
  ELSEIF ((Ni = 6 AND Nf=3) OR (Ni = 3 AND Nf=6)) THEN
    range = 790
    GOSUB move_servo
```

```
OUT0 = color
ELSEIF ((Ni = 6 AND Nf=2) OR (Ni = 2 AND Nf=6)) THEN
  range = 675
  GOSUB move_servo
  OUT5 = color
ELSEIF ((Ni = 6 AND Nf=1) OR (Ni = 1 AND Nf=6)) THEN
  range = 535
  GOSUB move_servo
  OUT6 = color
ELSEIF ((Ni = 5 AND Nf=4) OR (Ni = 4 AND Nf=5)) THEN
  range = 960
  GOSUB move_servo
  OUT0 = color
ELSEIF ((Ni = 5 AND Nf=3) OR (Ni = 3 AND Nf=5)) THEN
  range = 815
  GOSUB move_servo
  OUT0 = color
ELSEIF ((Ni = 5 AND Nf=2) OR (Ni = 2 AND Nf=5)) THEN
  range = 700
  GOSUB move_servo
  OUT4 = color
ELSEIF ((Ni = 5 AND Nf=1) OR (Ni = 1 AND Nf=5)) THEN
  range = 565
  GOSUB move_servo
  OUT6 = color
ELSEIF ((Ni = 4 AND Nf=3) OR (Ni = 3 AND Nf=4)) THEN
  range = 865
  GOSUB move_servo
  OUT0 = color
ELSEIF ((Ni = 4 AND Nf=2) OR (Ni = 2 AND Nf=4)) THEN

'DEBUG "calc_spectra - Ni and Nf are 4 and 2 combinations", CR
'DEBUGIN my_debug
'DEBUG CR

  range = 725
  GOSUB move_servo
  OUT3 = color
ENDIF

IF ((Ni = 4 AND Nf=1) OR (Ni = 1 AND Nf=4)) THEN
  range = 590
  GOSUB move_servo
  OUT6 = color
ELSEIF ((Ni = 3 AND Nf=2) OR (Ni = 2 AND Nf=3)) THEN
```

```
range = 745
GOSUB move_servo
OUT1 = color
ELSEIF ((Ni = 3 AND Nf=1) OR (Ni = 1 AND Nf=3)) THEN
range = 610
GOSUB move_servo
OUT6 = color
ELSEIF ((Ni = 2 AND Nf=1) OR (Ni = 1 AND Nf=2)) THEN
range = 625
GOSUB move_servo
OUT6 = color
ENDIF
```

```
RETURN
```

```
'-----END calc_spectra-----
```

```
'-----START move_servo-----
```

```
move_servo:
```

```
'DEBUG "Entering move_servo", CR
```

```
'DEBUG ? Ni
```

```
'DEBUG ? Nf
```

```
'DEBUGIN my_debug
```

```
'DEBUG CR
```

```
FOR x = 1 TO 50
```

```
  PULSOUT 14, range
```

```
  PAUSE 10
```

```
NEXT
```

```
RETURN
```

```
'-----END move_servo-----
```

### **13. References**

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