Apparatus Competition

2022 Summer Meeting of the American Association of Physics Teachers

AAPT 2022
PHYSICS EDUCATION®
SUMMER MEETING
July 9-13, Grand Rapids, MI

Sponsored by the

AAPT Committee on Apparatus

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Apparatus descriptions also available at:
http://www.aapt.org/Programs/contests/apparatus.cfm

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Apparatus Competition

2022 AAPT Summer Meeting

Grand Rapids, MI

Apparatus Title: Measuring the Band Gap Energy of a Semiconductor

Name: John W. Zwart

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Abstract (50-75 words): Low-cost modern physics experiments can be difficult to find. This lab exercise addresses that need, using a very inexpensive electrical component (a negative temperature coefficient (NTC) thermistor, typically used as a resistance thermometer), and common pieces of lab equipment (such as a DMM and thermometer) to determine the size of the energy gap between valance and conduction bands in a semiconductor.

Construction of Apparatus: An NTC thermistor is simply a piece of semiconductor with a pair of leads attached. Data collection for this experiment consists of measuring resistance as a function of temperature. A series of water baths are used to vary sample temperature. Since the as-purchased thermistor is not water resistant, wires were soldered to its leads and the sample made water proof by dipping in “Plasti Dip.”

Use of Apparatus: See separate file (ZwartBandGap2022) for a complete description of the experiment and materials list/budget

[Your description of the apparatus should explain how to construct and use the apparatus along with the educational value or use of the apparatus. Figures, pictures, sample lab write-ups, etc. may be included as appropriate. This description (made anonymous) will be available to the judges of the apparatus. This description will also be posted on the apparatus competition web page.]

Measuring the Band Gap Energy of a Semiconductor

John Zwart – Professor of Physics Emeritus
Dordt University
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Abstract
Low-cost modern physics experiments can be difficult to find. This lab exercise addresses that need, using a very inexpensive electrical component (a negative temperature coefficient (NTC) thermistor, typically used as a resistance thermometer), and common pieces of lab equipment (such as a DMM and thermometer) to determine the size of the energy gap between valance and conduction bands in a semiconductor.

Theory

For a sample of a conducting material, electrical resistance goes up with increasing temperature primarily due to increasing numbers of collisions between conduction electrons. However, for a semiconducting sample, the dominant contribution to temperature dependence of resistance is due to an increase in the number of conduction electrons with increasing temperature which causes the resistance to decrease as temperature goes up. This is due to thermal excitations of electrons from the valence to the conduction band. The size of the energy gap between the bands plays a key role in this increase in the number of conduction electrons as is shown below.

A sample's electrical resistance is related to its resistivity ρ, cross-sectional area A and length L by[1]:

$$R = \rho AL \qquad (1)$$

and, in the relaxation time approximation, the resistivity is[2]:

$$\rho = mne2\,\tau \qquad (2)$$

where m and e are the electron mass and charge, n is the number of conduction electrons per unit volume and τ is the relaxation time which measures the average time between conduction electron collisions during current flow. The inverse of the relaxation time typically varies as a power law of temperature (e.g. producing a linear dependence of resistance near room temperature for many metals).

While n is constant for conductors, for semiconductors it depends on temperature and is given by[3]:

$$n(T) \propto T1.5\; e-(Eg2kT) \qquad (3)$$

where E_g is band gap energy, k is Boltzmann's constant, and T is the sample temperature in Kelvin.

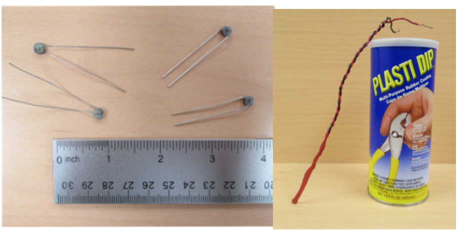
These three equations can be combined to relate resistance to temperature:

$$RT=R\infty\ e-(Eg2kT) \qquad (4)$$

One approximation has been used to arrive at equation (4). Since an exponential function varies much more rapidly than any power law, temperature power law terms coming from n and τ have been treated as constant. The combinations of constants in equation (4) is written as $R\infty$since this prefactor is the limiting value of resistance for large T.

<u>Experiment</u>

An NTC thermistor is simply a piece of semiconductor with a pair of leads attached. Data collection for this experiment consists of measuring resistance as a function of temperature. A series of water baths are used to vary sample temperature. Since the as-purchased thermistor is not water resistant, wires were soldered to its leads and the sample made water proof by dipping in “Plasti Dip.”



(a) (b)

Figure 1. NTC thermistors as-purchased (a) and as-prepared for measurement (b).

Data collection consists of filling a foam cup with water, inserting the sample and thermometer, waiting for thermal equilbium to be reached, using the DMM to measure resistance, and recording resistance and tempertature. Water baths varying in temperature from ice water to very hot provides a good range.

Once data is collected and temperatures are converted to Kelvin, an equation of the form

$$R = Ae^{B/T} \qquad (5)$$

is fit to the data and the fitting parameter B is used to find the band gap energy. The graph below shows a typical set of data and fit to equation (5).

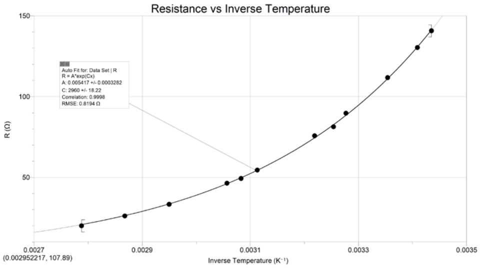


Figure 2. Resistance versus inverse temperature data and equation fit.

Here the fitting parameter B is 2960 K. Setting that equal to the constant in the exponent from equation (4), 2960 K = $E_g/2k$, yielding a band gap energy of 0.51 eV.

Conclusion

Using a low cost electrical component and common pieces of lab equipment allows for the determination of a quantum mechanically derived quantity, the band gap energy of a semiconducting material. This lab exercise also introduces students to electrical properties of semiconductors as well as resistance thermometry.

References

1. Jearl Walker, David Halliday, Robert Resnick **Fundamentals of Physics** 10th ed Wiley, Hoboken New Jersey 2014, p 755.
2. Walker, p 759.
3. Neil W. Ashcroft and N. David Mermin **Solid State Physics** Holt Rinehart Winston, NY 1976 p 575.

Materials List

NTC Thermistor $1.16 each from Digi-Key electronics (digikey.com) part number 495-76832-ND. Price per unit is reduced if buying in quantity (e.g $0.70 each if buying 50).

Thermometer $10.95 from American Science & Surplus (sciplus.com) part number 94966P1.

Digital Multimeter $11.75 from American Science & Surplus (sciplus.com) part number 97228P1.

Plasti Dip $9.89 was purchased from a hardware store. It is readily available at places such as Lowes, The Home Depot, and some automotive supply stores.

Miscellaneous items used that are generally available in a typical lab include foam cups, clip leads, soldering iron and solder, and wire.

A total of $33.75 + ~$10 shipping were spent on items specifically used in this lab.

Apparatus Competition

2022 AAPT Summer Meeting

Grand Rapids, MI

Apparatus Title: Pasco Gyroscope Motor

Name: Paul Noel

Address: 1010 State St
Apt 6
New Haven, CT 06511

Phone: (989)450-9465

e-mail: paul.noel@yale.edu

Abstract (50-75 words):

Construction of Apparatus:

Use of Apparatus:

[Your description of the apparatus should explain how to construct and use the apparatus along with the educational value or use of the apparatus. Figures, pictures, sample lab write-ups, etc. may be included as appropriate. This description (made anonymous) will be available to the judges of the apparatus. This description will also be posted on the apparatus competition web page.]

Motorized Gyroscope

Abstract

The Mitac gyroscope has been a staple in physics lecture demonstrations for decades, but it is no longer being produced. To get a suitable replacement, a Pasco gyroscope was modified with a variable speed and direction motor. The motor is battery powered and is housed in a 3d printed structure.

Construction of Apparatus

The modified gyro consists of the Pasco Gyroscope ME-8960, 5 3d printed parts, a lipo battery, motor, rubber contact wheel, electronic speed controller (esc), and counterweights. The counterweights below the 3d printed parts move the center of mass of the additional parts to support rod. This prevents off axis torque, allowing the gyro to be used at any angle.

Use of Apparatus

The large disk of the apparatus makes it ideal for lecture demonstrations. This apparatus can also be used for quantitative lab investigations with the addition of a digital tachometer to measure the rotational speed of the disk.

Apparatus Competition Entry Form
2022 AAPT Summer Meeting
Grand Rapids, MI

Name: Paul Nord

Institution: Valparaiso University

Address: 1610 Campus Drive

Valparaiso, IN 46383

Phone: 219-508-7874

Fax:

E-mail: Paul.Nord@valpo.edu

Support required for apparatus:

Can this apparatus be constructed for under $100? yes■* no☐**

***If yes, you must also provide a materials list with your apparatus description including prices and vendors of each item. Your apparatus will then be considered for both the unlimited cost and the low cost categories of the competition. Please see additional rules for the low cost category.

Approximate size (width and depth of table and/or floor space)

Does this apparatus require Electrical Power? yes☐ no■

Will you be present to set up your apparatus? yes■ no☐

If no, who will be setting up the apparatus?

(It is possible for the apparatus to be shipped to the meeting and then setup by the competition director. But be sure to make prior arrangements with the competition director before doing so.)

When do you plan to set up your apparatus (on Sunday July 10)?

12-3 PM■ I need to arrange a different time (contact the competition director).☐

What day do you plan to take down your apparatus? It is preferred that all apparatus be displayed until Wednesday, July 13. Wednesday, noonish

Other support needed for the proper operation of this apparatus:

Apparatus Competition

2022 AAPT Summer Meeting

Grand Rapids, MI

Apparatus Title: Magnetic Crystal Lattice

Name: Paul Nord

Address: 1610 Campus Drive
Valparaiso, IN 46383

Phone: 219-508-7874

e-mail: Paul.Nord@valpo.edu

Abstract (50-75 words): This array of large compass needles demonstrates the coupling between magnetic atoms in a crystal lattice. Large size allows easy viewing and hands-on activities. Coupling between near and distant needles is easily observed.

Construction of Apparatus: 10 Magnetic Needles, 4" (100mm) - Eisco Labs $25
Acrylic Sheet 12''x24'' 1/8" $50 Laser Cut

Use of Apparatus: Model of the behavior of a magnetic material in a magnetic field. (PIRA 5G20.30)

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Apparatus Competition

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Grand Rapids, MI

Apparatus Title: Planck's Rainbow

Name: Paul Noel

Address: 1010 State St
Apt 6
New Haven, CT 06511

Phone: (989)450-9465

e-mail: paul.noel@yale.edu

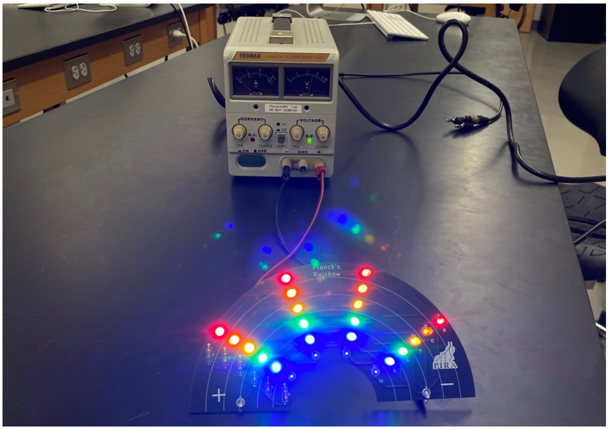
Abstract (50-75 words):

Construction of Apparatus:

Use of Apparatus:

[Your description of the apparatus should explain how to construct and use the apparatus along with the educational value or use of the apparatus. Figures, pictures, sample lab write-ups, etc. may be included as appropriate. This description (made anonymous) will be available to the judges of the apparatus. This description will also be posted on the apparatus competition web page.]

Planck's Rainbow



Abstract

The Planck's Rainbow shows the relationship between turn on voltage and the wavelength of light produced. It accomplishes this by having 6 identical branches, where each branch contains a resistor and 4 LEDs of the same color. This is done to get around the close turn on voltage between colors. This device is ideally powered by a hand generator. The faster the generator is spun, the more branches light.

Construction of Apparatus

The device is simple to construct using the provided schematic in the appendix. In the kit form, simply install the resistors and LEDs in the PCB, being mindful of the LED direction. Then solder the components in place.

Use of Apparatus

The Planck's Rainbow is best used as a demo for small groups. A hand crank generator is the most effective way of demonstrating this device. A power supply can be used, if needed. For the hand crank generator, have students go from slow to fast.

A version of this using a capacitor with a single LED of each color exists, but the capacitor adds unnecessary complexity for student understanding.

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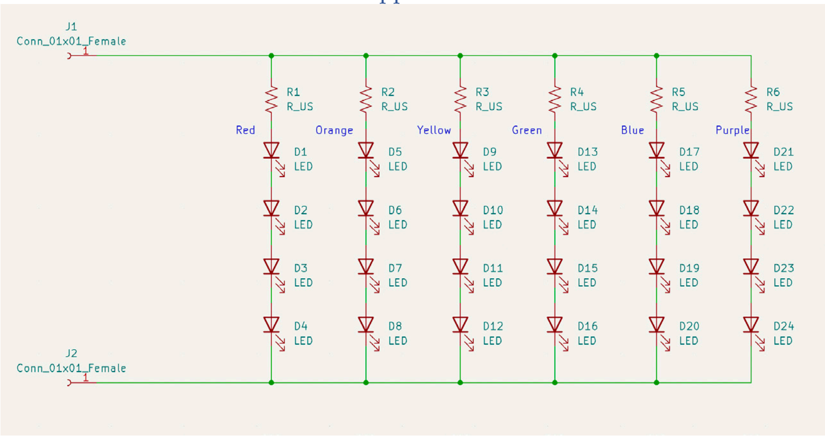
Bill of Material

Component	Quantity	Cost	Total
220 ohm Resistor	6	0.01	0.06
Red LED	4	0.02	0.08
Orange LED	4	0.02	0.08
Yellow LED	4	0.02	0.08
Green LED	4	0.02	0.08
Blue LED	4	0.02	0.08
UV LED	4	0.02	0.08
PCB	1	0.97	0.97
			1.51

Appendix



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