RADIATION SHIELDING

Lab NUCL 4

Adapted from Vernier Technology

(PA Standards for Sci & Tech 3.1.12, 3.2.12, 3.4.12, 3.6.12, 3.7.12, 3.8.12)

INTRODUCTION

Alpha, beta, gamma, and X-rays can pass through matter, but can also be absorbed or scattered in varying degrees, depending on the material and on the type and energy of the radiation. Medical X-ray images are possible because bones absorb X-rays more than soft tissues. Strongly radioactive sources are often stored in lead boxes to shield the local environment from the radiation.

Some materials absorb beta rays. A sheet of common cardboard will absorb some of the betas, but will allow most to pass through. This absorption can be measured by fixing a beta source and a radiation monitor so their positions do not change, and then inserting layers of cardboard between them.

When an absorber is in the path of beta rays, it will allow a certain fraction, f, to pass through. The fraction depends on the density and thickness of the absorber, but will be a constant for identical absorbers and fixed beta-ray energy. If the number of counts detected in a count interval is N_0 when no absorber is in place, then the counts, N, with the absorber, will be $N = f N_0$

A small source of beta radiation will be used for this experiment. Beta rays are high-energy electrons.

PURPOSE

In this experiment, a radiation counter will be used to study how the radiation emitted by a beta source is absorbed by cardboard.

EQUIPMENT/MATERIALS

Vernier computer interface
computer
Vernier Radiation Monitor
weighing paper
ten 10cm square cardboard pieces
ring stand and ring clamp
Strontium-90 0.1 µC beta source
scotch tape and ruler
test tube clamp
forceps

SAFETY

- Always wear safety glasses in the lab.
- DO NOT eat or drink in the lab.
- Wash hands when the lab experiment is complete.
- Wear gloves and an apron when handling an open source.

PROCEDURE

Test the Absorption of Beta Radiation by Matter

1. Place a circle piece of a weigh boat on the lower right hand corner of the ring stand base. Place the Sr-90 beta source on top of paper(unmarked side up). Attach ring clamp to ring stand. Attach the top of the radiation monitor to the test tube clamp and then to the ring clamp with the detector pointing down at the Sr-90 source. Move the Sr-90 source around on the weighing paper using forceps to determine the most sensitive place on the detector.

2. Raise the monitor so that there is enough room between the monitor and the Sr-90 source for 10 layers of cardboard, about 4.5 cm. Do not move the source or monitor during the experiment. Remove all of the cardboard layers from between the source and monitor.

3. Connect the radiation monitor to SONIC/DIG 1 of the Vernier computer interface. Connect the interface to the computer with the proper cable.

4. Open Logger *Pro 3.3* program on the computer. Open Ad. Chemistry w/Vernier. Open the file “28 Shielding.” If computer does not recognize the interface and monitor, Left click on Experiment in menu bar. Left click on connect interface; Select Lap Pro. Select radiation monitor.

5. Click [Collect] to begin the data collection. LoggerPro will count the number of beta particles that strike the monitor over a 50-second count interval.

6. After at least 50 seconds have elapsed, a red dot will appear on the screen at x-coordinate-5 and y-coordinate-100. Click [Keep]. In the entry field that appears, type “0”, the number of layers of cardboard in place. Press OK to complete your data entry. The data collection will now pause for you to add a layer of cardboard shielding.

7. Insert one layer of cardboard between the source and monitor. Be sure that the cardboard completely covers the source’s “view” of the Geiger tube in the monitor. Click “continue” to start the next count interval.

8. After at least 50 seconds have elapsed, click [Keep]. Type “1” (one layer of cardboard) and press OK.

9. Repeat Steps 11 and 12, adding one layer of cardboard at a time, until data for 10 layers has been collected.

10. Click [Stop] to end the data collection.

11. Record the results onto Data Table 1.

12. Click on curve fit (icon left of clock icon). Scroll down to (Base-10 exponent); Click try fit. Hit OK.

13. Copy equation and the values for A and B onto Data Table 2.

Name____________________
Name____________________
Period___________________
Date_____________________

RADIATION SHIELDING

DATA TABLE

Table 1

Layers of cardboard shielding	Counts/Min
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

Table 2

Equation, And B Values	

DATA ANALYSIS

1. Graph of layers of cardboard shielding vs. counts/minute.

2. Using the information in Table 2, write the equation for the graph.

3. Use the equation from question # 2 and $10^B = f$, determine the fraction, f, of beta rays transmitted, on average, per layer of cardboard. Hint: $N = f\,N_0$.

RADIATION SHIELDING
Teacher's Notes

1. Because the radiation monitors detect the arrival of individual particles, Poisson statistics apply. The more counts that arrive in a counting interval, the better the precision. The standard error of a count of n is $n^{1/2}$, so do not be surprised to see considerable run-to-run variation in the many-layer points where n is only ten or twenty.

2. This activity asks students to generalize the transmission through zero, one, two, three…absorbers of f^0, f^1, f^2, f^3, to the transmission through x absorbers: f^x.

3. It is critical that the geometry of the experiment remain constant as the absorbers are added. If either the monitor or the source is moved during data collection, the resulting run will probably be poor.

4. The final analysis question requires manipulating the fitted equation. Students who are weak in mathematics may need assistance with this step.

5. The analysis asks that the student chooses an appropriate fit equation based on the mathematical form of the model. The model is an exponential function: $N = f^x \cdot N_o$. There are two exponential functions offered. One is a base-10 exponential function of y = A·10^(B·x), or $Y = A10^{Bx}$. Another is a natural exponential function of y = A·exp(–C·x) + B, or $Y = A^{-Cx} + B$. The different base of the exponential function does not affect the shape of the function, but the natural exponential has the extra additive term of "+B". Because the count rate is usually significantly higher than background, the additive term will have little effect on the fit. As a result, either function could be chosen for this experiment. The additive term does affect the fit slightly, however, so the exponential parameter will not be directly comparable in the two fits (aside from the base change). Since the base 10 exponential more closely matches the form of the model developed by students, it is the more natural choice, but either form can be used.

6. The cardboard used for the sample data was cut from a standard cardboard shipping box. The transmittance will vary with type and thickness of cardboard.

7. The source used in this activity is a pure beta source. No gamma rays are emitted, so there is no confounding effect of differing absorption of gamma and beta radiation by the shielding material.

ANSWERS TO THE DATA ANALYSIS QUESTIONS

1. Answers will vary. For the sample results, the graph does indeed follow the model.
2. Answers will vary. For the sample data, the equation is: $Y = 1845 \times 10^{(-0.125x)}$.
3. Answers will vary. For the sample data, the data does match the model fairly well, especially for the larger numbers of layers of absorbers. It appears that the simple multiplicative model does predict the transmission of radiation through matter.
4. Answers will vary. For the sample data, and using the base-10 fit, $10^{B} = f$. Solving the expression, $10^{-0.141} = 0.75$. One layer of cardboard transmits 75% of the beta particles striking it.

ANSWERS TO THE EXTENSION ACTIVITY

1. For longer collection times, the total number of counts in each interval will be longer. As a result, the precision of each measurement will be greater. We would expect less scatter about the model line. For shorter collection times, the precision will be reduced and we would see more scatter about the model’s function.
2. Background counts were made for the sample data. The average was 25 counts per 50 second interval. To correct for background radiation, subtract 25 from each of the data points collected using the source and the absorbers, and repeat the graphing and curve fit.
3. One layer of foil absorbs a much smaller fraction of the betas, so larger stacks of absorbers will be required. You could substitute ten layers of foil for each layer of cardboard.

SAMPLE DATA

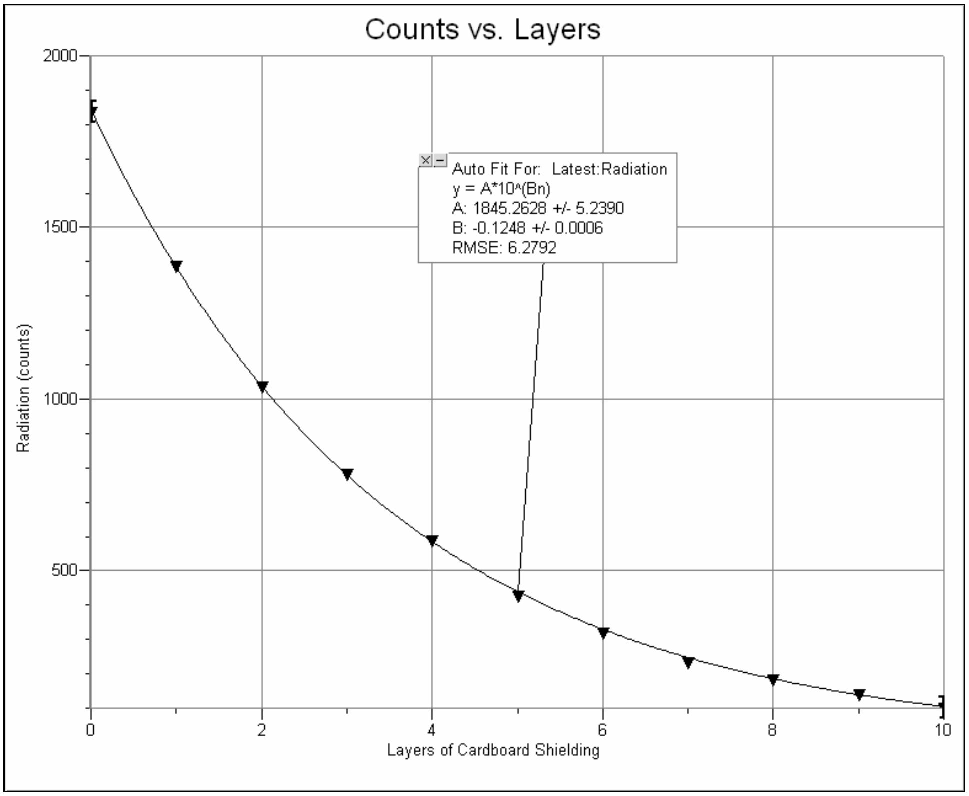
Layers of cardboard shielding	Counts/min
0	1840
1	1390
2	1038
3	785
4	592
5	430

Layers of cardboard shielding	Counts/min
6	323
7	238
8	186
9	143
10	103

Model equation, from Part I	$N = N_0 f^{x}$
Calculated equation, from Data Analysis	$Y = 1845 \times 10^{(-0.125x)}$

SAMPLE GRAPH

The model fits the experimental data well. The additional three points at lower left are measures of background radiation from cosmic rays; the background count rate was small compared to the count rate using the Sr-90 source.



Radiation count rate vs. layers of cardboard shielding