

The Journal of Undergraduate Research in Physics

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UNDERGRADUATE RESEARCH AND THE TEACHING OF PHYSICS - IS KNOWING THE FACTS ENOUGH?

An Editorial by Rexford E. Adelberger

I spent some time at the January meeting of the APS and the AAPT in Washington DC walking through the exhibits of textbook publishers and the slick scientific equipment companies. It seemed to me that anything I wanted to know about physics was available in a expensive thick book or could be experimentally investigated with a special expensive piece of equipment. I left the exhibit hall with the realization that that physics and latin had a lot in common...both were dead subjects. There was nothing new happening in either field.

On the way to drowning my sorrows in one of the expensive corners of the hotel, I passed by some rooms where physicists were talking about the research they were doing to understand exotic things such as superconductors, supernova, exitonic fluids, volcanism and mantle plumes in the earth. What these people were saying was really exciting. Physics wasn't dead. Physics wasn't a logical collection of facts and problems with answers in the back of the book (even numbered ones only). Physics was a search of understanding of the world around us.

Wow!!! This sounds exciting. I wonder how people who are presently taking Freshman Physics are ever going to find out that this is true. Certainly not from the large number of cloned physics texts that are currently available. Certainly not from the slick 'black boxes' that can measure all sorts already known constants.

There is a serious dilemma in the commercial packaging of undergraduate physics and what a student should get from their education. This conflict is part of the reason so few people are going into physics these days. When we teach physics, especially introductory physics, we present a bunch of facts that one only has to look up. We assign problems with simple answers, ones that fit the subheadings of the text we are using. The standardized tests, such as the GRE, divide up their questions according to the subtopic topic you 'need to understand'. The research talks to which I lis-

tened those few days in Washington didn't seem to limit themselves to the appropriate subtopic. Nature doesn't seem to know about the subtopics of physics.

How does one go about teaching the process of learning about nature called physics instead of how the ancients did physics? The only way of doing this of which I am aware is to get the student involved in research from the beginning. Freshmen should be going research. They should be searching for the understanding rather than being told the answers. The search for knowledge has always been a seductive endeavour for bright young people.

If you want to include undergraduate students in research projects, one has basically two possibilities. The first is to have an ongoing faculty research project into which the student can plug. However, a number of the small colleges, which produce most of the physics majors in the US, do not have such programs. If that is the case, then the faculty must provide other means for beginning students to learn to become physicists. Perhaps we should be teaching from journals rather than teaching from textbooks. In a few of the schools in the US, students are eventually forced to get involved in research when they are required to do a senior thesis, but it comes too late. By the senior year, too many of the bright students are majoring in business instead of physics.

I realize that it is asking a bit much of the community of physics teachers to change the way we have been teaching physics for most of our lives to return to the teaching methods of the 18th century. During that period, if one wanted to learn physics, one went to work for one of the physicists as a lab assistant. One studied physics by being actively involved in research. I also know that the publishing companies and the lab equipment companies have great inertia. It is unlikely that we will see on the shelves of the bookstore, despite the current popularity of a new approach to the content of

freshman physics texts, a book that teaches an undergraduate student how to be a physicist. However, a start in this direction might be for more schools to require a thesis from all physics majors.

In many institutions, the type of research that is done for senior thesis is not of the quantity or quality that appears in the major research journals. These archival research journals were established to record the major research works, not the narrow time limited research that is done by undergraduate students. In the past, the physics done by large numbers of undergraduates was not communicated and remained unrecognized.

When undergraduates do significant but not extensive research and we do not encourage them to publish, even though we are really teaching physics, we are only doing half the job. What good is it to search for knowledge, find some and then tell no one about it? Leonardo daVinci was not much of a physicist. While he was bright and thought about a lot of things, he did not communicate them to his peers. Someone else had to re-invent all that knowledge.

The Journal of Undergraduate Research in Physics, where undergraduate research can be published and disseminated to all members of the Society of Physics Students, is a vehicle we can use to finish the job of teaching our students how to be physicists. Supervising research and encouraging the students to submit their work for publication are labor intensive undertakings. Many of us are too busy being physicists ourselves to take the time to start the next generation on its way. If there is no new generation, what will happen to physics? Perhaps it will take its place with the study of Babylonian in the classical language departments at a few of the major universities.

EFFICIENCY FOR COUNTING A LARGE SOURCE OF γ - RAYSM.G. Prahovic ^a and R.W. Tramel ^bDepartment of Physics
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ABSTRACT

An approximate solution to the problem of calculating the efficiency for detecting γ - rays emitted from a large cylindrical source is presented and discussed.

INTRODUCTION

The calculation described in this paper was performed in connection with the data analysis of a nuclear physics experiment. The experiment was an attempt to detect bound systems of neutrons, i.e., clusters of four or five neutrons bound together by the strong nuclear force. A beam of ^{50}Ti nuclei incident upon a target of ^9Be was used to form the neutron-rich compound nucleus ^{59}Fe . It was felt that perhaps one of the decay modes would be the emission of neutron clusters. In the experiment, "reverse kinematics" were used: a heavy projectile nucleus (^{50}Ti) collided with a light target nucleus (^9Be). The effect of this would be to "focus" any emitted neutron clusters in the forward direction, the direction of the ^{50}Ti beam. To detect the clusters, a jar containing approximately 1 kg of Sc_2O_3 powder was placed "downstream" from the ^9Be target. The powder was isotopically pure in ^{45}Sc . If two or three neutrons were to be deposited in a nucleus of ^{45}Sc by a neutron cluster, a neutron-rich, unstable nucleus, ^{47}Sc or ^{48}Sc , would be formed. These nuclei emit β -delayed γ -rays of distinct energies which can be detected. The most intense γ -ray lines have energies shown in Table 1.

After being activated for about four days, the emis-

sions from the Sc_2O_3 sample were counted for several days using six Ge γ -ray detectors. These detectors were positioned so as to encircle the activated sample. γ -ray spectra were stored on magnetic tape. Further details concerning the experiment are described elsewhere.¹

The object of the data analysis for the experiment was to determine the cross section for the production of neutron clusters of varying numbers of neutrons. The calculations to be described here made an important contribution to this analysis by determining the efficiency for counting a large source (the Sc_2O_3 sample) for a γ -ray energy of interest. Here, "efficiency" means the ratio of the number of γ -rays of a given energy that were counted by the six-detector system to the total number of γ -rays of

Table 1
 γ -rays emitted by ^{47}Sc or ^{48}Sc

159.38 keV
889.25 keV
983.501 keV
1037.496 keV
1120.52 keV
1312.087 keV

that energy emitted by the sample during the time that it was counted. Six efficiencies were calculated in all, one for each of the six γ -ray energies of interest. What follows is a description of how the efficiency was calculated and the several simplifying assumptions that were made to make the calculation tractable.

DIVISION OF THE SAMPLE INTO VOLUME ELEMENTS

In the interest of simplicity, it was assumed that the Sc_2O_3 powder used to detect the neutron clusters was in the form of a right circular cylinder, and that it had been uniformly activated by the clusters. Cartesian coordinates were used throughout the calculation because they resulted in a much simpler algorithm for determining the efficiency. The cylinder of powder was divided up into a large number of very fine volume elements in the form of right rectangular parallelepipeds, all of the same size. To accomplish this, first a grid was laid upon the circular cross section of the cylinder. The grid was formed by taking a square with an edge length equal to the diameter of the circle and dividing it into square elements of equal size. Using a rectangular (x,y) coordinate system with its origin at the center of the circle, the center of each square element was assigned an (x,y) coordinate. If the distance from the center of a square element to the center of the circle was less than or equal to the radius of the circle, the element was retained in approximating the area of the circle. Thus, the circular cross section of the cylinder was approximated by an array of square elements, with the central point of each element falling within or on the circle. Next, the height of the cylinder was divided into elements of uniform size, forming the parallelepipeds.

A three dimensional (x,y,z) rectangular coordinate system was established with the axis of the cylinder lying along the z-axis. The plane perpendicular to the cylinder axis and dividing the cylinder into two equal halves was taken to be the xy plane (the $z = 0$ plane). The center of each element was taken to be a point source of γ -rays. Each point source was assumed to emit γ -rays uniformly in all directions and at the same rate.

ASSUMPTION OF SPHERICAL DETECTOR CRYSTALS

An important simplifying assumption was made regarding the geometry of the γ -ray detectors used to count the γ -rays emitted from the jar of Sc_2O_3 powder. The Ge crystal of each detector, the primary component used in detecting and determining the energy of a γ -ray, was assumed to have the shape of a sphere. In fact, the crystals are cylindrical in shape. However, it was felt that a sphere with a volume comparable to that of a given detector crystal would serve as a reasonable approximation to the shape of a cylinder and simplify the calculation of the overall efficiency. After examining crystal specifications for some of the detectors, the radius of each sphere associated with a detector was taken to be 2.5 cm.

A commercially available radioactive standard, containing eight radioisotopes, was used for three calibrations of the six detectors. For each calibration, the standard source was placed in three different positions along the cylinder axis of an empty jar and the γ 's counted. All of the detectors and the jar were in the exact positions that would be used for counting the activated Sc_2O_3 powder. The source emitted γ -rays of several different energies, which provided the data points needed for plotting a point-source efficiency curve for each detector. The actual data points obtained for each detector in the calibration fell approximately along a straight line in a plot of point source efficiency versus the base-10 logarithm of γ -ray energy. A weighted linear least-squares fit was used to find the equation of the line that best fit the data. This was used to calculate the efficiencies of each detector for the six γ -ray energies that would serve as a signature for the detection of neutron clusters.

CALCULATION OF EFFICIENCY ASSUMING NO ATTENUATION

For a given γ -ray energy, the efficiency ϵ_i of a detector with an idealized spherical crystal for the i^{th} source location was taken to be:

$$\epsilon_i = (\Omega_i/4\pi) P_i, \quad (1)$$

where Ω_i is the solid angle subtended at a point

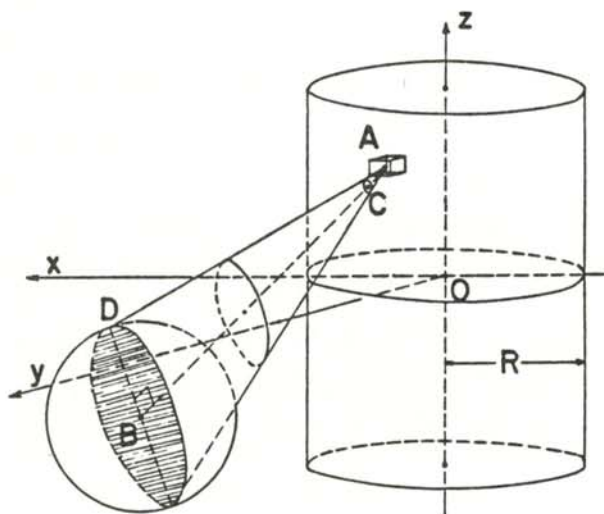


Figure 1

The geometry involved in the efficiency calculation. The shaded cross-section of the detector sphere is the detector "disk". The i th point source of the γ -rays is located at the center of the i th volume element at A, which has coordinates (x_{si}, y_{si}, z_{si}) . The center of the detector sphere is located at B, which has coordinates $(0, y_d, z_d)$. The linear distance from A to B is r_i . The point at which line segment AB intersects the cylinder wall is located at C, which has coordinates (x_i, y_i, z_i) . Angle BAD is the half-angle of the solid-angle cone. The radius of the cylinder is R.

source by the "spherical" Ge crystal. The quantity P_i represents the average probability that a photon, falling within the solid angle subtended by the detector, will be detected. For any given point source a fixed distance away from the center of the Ge crystal, P_i should be nearly constant if treating the crystal as a sphere is a valid approximation.

The geometry for the general case involving an arbitrary source located in one of the cylinder elements is shown in Figure 1. This case will be considered later. However, the figure is sufficient to depict the geometry being considered for the present discussion. r_i is the linear distance from the source in a particular calibration position to the center of the Ge sphere of the detector. The sphere's center is assumed to fall in the $x = 0$ plane, it has only y and z coordinates (y_d and z_d). The radius of the sphere is denoted by r_d . The sol-

id angle subtended by the sphere at the location of a source somewhere on the z axis (the cylinder axis) was approximated by the solid angle that would be subtended at the source location $(0, 0, z_{si})$ by the detector "disk" of radius r_d . This disk is perpendicular to the line segment joining the source and the center of the detector sphere (see Figure 1). This approximate solid angle is given by:

$$\Omega_i = 2\pi (1 - \cos \theta_i), \quad (2)$$

where θ_i is the half-angle of the solid-angle cone. From Figure 1, one can see that:

$$\cos \theta_i = r_i / \{r_d^2 + r_i^2\}^{.5}, \quad (3)$$

where

$$r_i = \{y_d^2 + (z_d - z_{si})^2\}^{.5}. \quad (4)$$

Thus,

$$\epsilon_i = [P_i / 2] [1 - r_i / \{r_d^2 + r_i^2\}^{.5}]. \quad (5)$$

Solving for P_i gives:

$$P_i = 2 \epsilon_i / [1 - r_i / \{r_d^2 + r_i^2\}^{.5}]. \quad (6)$$

When the P_i 's for a given detector were compared with each other, they were found to differ by as little as 0.1% and as much as 27%. Typical agreement was to within 10%. In the calculation of efficiency of the overall system for a particular γ -ray energy, the three P_i 's for a given detector were averaged together to arrive at a value of P , the probability that a photon incident upon a detector would be detected, independently of the distance between the source which emitted the photon and the center of the detector sphere. In fact, the distance between the source and the center of a detector sphere was different for each of the three calibration points. As a result, the P_i 's would vary somewhat from one calibration point to the next, even if the Ge crystals were actually spheres. However, these variations are expected to be small, especially for the higher energy γ -rays being considered. The average P is estimated to be accurate to within a few percent. It is, without doubt, the quantity introduc-

ing the greatest uncertainty in the calculation as a whole.

INCORPORATING ATTENUATION INTO THE CALCULATION

In calculating the overall efficiency of the system, it was necessary to account for the attenuation of γ -rays by the Sc_2O_3 powder in the jar. The attenuation of γ -rays in matter is described by:

$$I = I_0 \exp[-\mu r]. \quad (7)$$

The quantity I_0 represents the unattenuated intensity of the beam of γ -rays, I is the intensity of the beam after it has traveled a linear distance r through the material from the source and μ is the total linear absorption coefficient for the material which attenuates the beam. μ is characteristic of the material. It was determined for our sample using formulae for composite materials² and our measured density for the Sc_2O_3 powder in the jar. Thus, the probability that a photon will not be absorbed by the material (via Compton scattering, the photoelectric effect or pair production) is given by $e^{-\mu r}$.

Now we must calculate the average distance traveled by the photon through the powder for a given source position. The point A (x_{si}, y_{si}, z_{si}) shown in Figure 1 corresponds to the location of a source of γ -rays at the center of the i^{th} element of the jar. The center of the detector is located at B ($0, y_d, z_d$). The line segment connecting these two points has the parametric equations:

$$\begin{aligned} x &= x_{si} - x_{si} t \\ y &= y_{si} + (y_d - y_{si}) t \\ z &= z_{si} + (z_d - z_{si}) t, \end{aligned} \quad (8)$$

where $0 \leq t \leq 1$. Using these parametric equations, it was possible to determine at which point the segment joining the source and the center of the sphere would intersect the outside surface of the cylinder of Sc_2O_3 powder. We denote this point of intersection as (x_i, y_i, z_i), and define:

$$\begin{aligned} m_y &= [-x_{si}] / [y_d - y_{si}] \\ b &= -m_y y_{si} + x_{si} \end{aligned}$$

$$\begin{aligned} a_1 &= m_y^2 + 1 \\ b_1 &= 2m_y b \\ c_1 &= b^2 - R^2, \end{aligned} \quad (9)$$

where R is the radius of the cylinder. Solving for (x_i, y_i, z_i), one obtains:

$$\begin{aligned} x_i &= m_y y_i + b \\ y_i &= \{-b_1 + (b_1^2 - 4 a_1 c_1)^{.5}\} / 2a_1 \\ z_i &= z_{si} + [z_d - z_{si}] [y_i - y_{si}] / [y_d - y_{si}]. \end{aligned} \quad (10)$$

Thus, the distance which the γ -ray photon from the source must travel through the Sc_2O_3 powder, assuming its path follows the line segment joining ($0, y_d, z_d$) and (x_{si}, y_{si}, z_{si}), is:

$$r_a = \{ (x_{si} - x_i)^2 + (y_{si} - y_i)^2 + (z_{si} - z_i)^2 \}^{.5}. \quad (11)$$

We use r_a to approximate the average distance traveled by the photons through the powder for a given source position, where the average is over the solid angle subtended by the detector. Then, the efficiency of a detector for counting a source at (x_{si}, y_{si}, z_{si}) for a given γ -ray energy is given by:

$$\epsilon_i = (\Omega_i / 4\pi) P_i \exp[-\mu r_a]. \quad (12)$$

Using the approximation of Equations 2 & 3, where:

$$r_i = \{ x_{si}^2 + (y_{si} - y_d)^2 + (z_{si} - z_d)^2 \}^{.5}, \quad (13)$$

Equation 12, the efficiency for detecting γ -rays from a source at the center of the i^{th} element of the cylinder, becomes:

$$\epsilon_i = (P_i / 2) (1 - \cos \theta_i) \exp[-\mu r_a]. \quad (14)$$

AN EXPRESSION FOR THE OVERALL EFFICIENCY

If the cylinder of Sc_2O_3 powder is divided into M elements, there will be M sources of γ -rays, one at the center of each element. Denoting the efficiency for the i^{th} element of the cylinder for the j^{th} detector as ϵ_{ij} , the overall efficiency of the entire system of

$$\epsilon_s = \sum_{j=1}^6 \sum_{i=1}^M \frac{\epsilon_{ij}}{M} \quad (15)$$

six detectors, ϵ_s , is given by:

where it is assumed that all the γ -ray sources in the cylinder emit the same number of photons of a given energy in a given time interval. In order to obtain an accurate value for ϵ_s , the cylinder must be broken up into a great number of volume elements. A computer program was written to calculate a value of ϵ_s for each of the six γ -ray energies of interest. The values of ϵ_s ranged from 0.0085 for 1312 keV γ -rays to 0.0398 for 159 keV γ -rays. The overall uncertainty arising from the simplifying approximations is estimated to be less than 10%. The results were used elsewhere¹ to calculate the cross sections for producing neutron clusters.

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REFERENCES

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McMinnville, TN 37110.
1. Kozub, R.L., and M.G. Prahovic, to be published.
2. Evans, R.D., The Atomic Nucleus,
McGraw-Hill Book Co., Inc., New York,
1955, Ch. 25.

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A COMPUTER PROGRAM WHICH ILLUSTRATES SEVERAL FEATURES OF QUANTUM MECHANICS

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ABSTRACT

A set of individual programs to calculate and display a number of features of quantum mechanics have been combined to provide a program in which the user can select a number of rather complicated demonstration programs on an inexpensive microcomputer (a Sinclair QL). Details of the programming and the resultant displays are presented.

INTRODUCTION

This project involved the development of three graphical computer simulations of different aspects of quantum mechanics. The first, "deBroglie Waves", illustrates the concept of pilot waves in simple circular orbits. The second, "Probability Densities", shows radial probability densities of electrons in one electron atoms for different quantum states. The third, "Gaussian Waves", is a simulation of free wave propagation of a Gaussian shaped wave. The purpose of these programs is to give the user visual simulations as aids in understanding the concepts.

The parts of this program are written in SuperBASIC on a Sinclair QL computer¹. The three programs were run and tested individually. They were then converted to a SuperBASIC procedure and merged into one main menu-driven program. The menu allows the user to choose which of the three simulations are to be displayed. The desired procedure is called by using its title as a SuperBASIC command. After each simulation is run, the program allows the user to return to the main menu. Additional simulations could be added as procedures which are called by the menu.

There are two excellent compilers² for QL Super-

BASIC which considerably speed up the execution of this program. The SuperBASIC listing, which is available³, serves much like a source deck or source file in FORTRAN.

DEBROGLIE WAVES

The first program simulates deBroglie electron pilot-waves bound to a nucleus. Bohr's atomic theory included the postulate that electrons could only occupy discrete stable orbits. However, there was

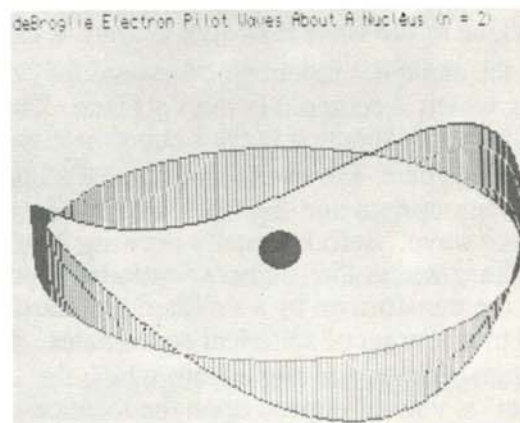


Figure 1

deBroglie pilot waves with 2 wavelengths in the orbital circle. The viewing angle is 30 degrees above the horizontal

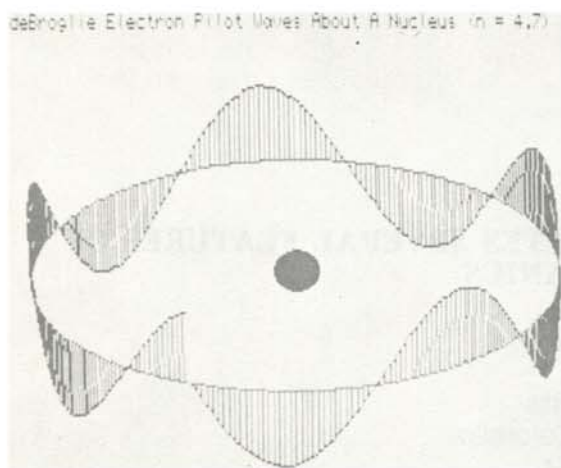


Figure 2

deBroglie pilot waves with 4.7 wavelengths in the orbital circle. The discontinuity shows that this is a non-allowed state. The viewing angle is 30 degrees.

no underlying explanation for why the electrons should occupy only discrete orbits until Louis deBroglie suggested that electrons might have wave characteristics as well as particle characteristics. Under this assumption, Bohr's quantization of angular momentum followed directly from combining the deBroglie wavelength for the pilot waves

$$\lambda = h/p, \quad (1)$$

with the standing wave condition that an integer number of wavelengths fit in the orbital circle.

The deBroglie wave and the orbital circle are treated as an "object" in cylindrical coordinates (r, θ, ϕ) . The value of the wave function, $\sin(n\theta)$, is calculated as the angle θ is incremented around the orbital circle, which is centered in the x, y plane. The value of the wave function is the z coordinate value for each r, θ pair. For each increment $\delta\theta$ around the circle, appropriate line segments are drawn to illustrate the wave. Before actually drawing them, these lines within the "object's" cylindrical coordinates are transformed by a standard graphical routine⁴ to a new set of spherical coordinates. The size, perspective, and angle from which the "object" is viewed depend upon the location of the viewer's eye and of the screen on which the final lines are to be drawn. Both of these positions are expressed in the spherical coordinates. This routine, contained in the procedure "convert", com-

putes the screen coordinates (cx, cy) corresponding to the line segments in the object coordinates.

The sub-program allows the user to select the number of full wavelengths in the orbital circle, the amplitude of the wave, and the angle of the eyepoint above the plane of the orbit. A special feature of the sub-program is that the user can choose any number of integer wavelengths for the deBroglie waves, or can choose to display the picture for a non-integer number of wavelengths. In this latter case, the lack of continuity for the wave is evident. Figures 1 - 3 are photographs of the results of this sub-program, taken directly from the monitor screen. The colors were temporarily changed to black-on-white for best reproduction.

PROBABILITY DENSITIES

The second sub-program gives a graphical display of the two-dimensional radial probability densities in one electron atoms. Four different quantum states are included in the display. The eigenfunctions used, $\psi_{n,l,m}$, where n is the principle quantum number, l is the angular momentum quantum number, and m is the projection of the angular momentum, are solutions to Schrodinger's equation in three dimensions. They can be found in many quantum mechanics textbooks.⁵ The four functions for which probabilities can be displayed are $\psi_{1,0,0}$, $\psi_{2,0,0}$, $\psi_{2,1,0}$, $\psi_{3,0,0}$. The equation:

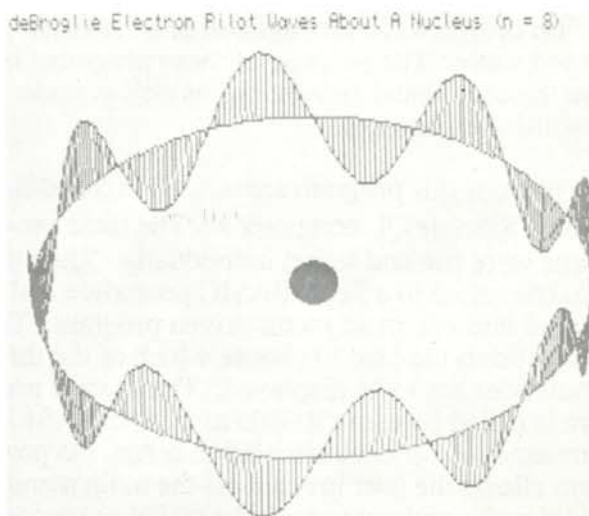


Figure 3

deBroglie pilot waves with 8 wavelengths. The viewing angle is 45 degrees.

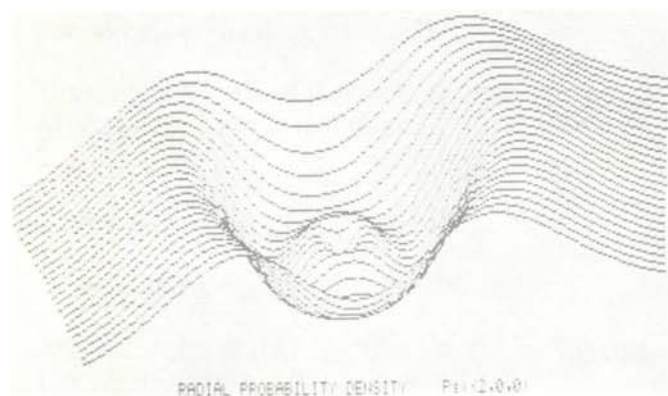


Figure 4

Radial probability density for a single electron atom, illustrating the $\psi_{2,0,0}$ eigenstate.

$$z = P(r,\theta) = (\psi_{n,l,m}^* \psi_{n,l,m}) r^2 \quad (2)$$

is used to calculate the radial probability per unit volume as a function of r and θ .

The function z is used to draw a two-dimensional surface plot. Such plots are commonly discussed in texts on computer graphics.⁶ The value of the function gives the height above the two-dimensional x,y plane. The values of z form the third dimension. In reality, a complete plot of the electron probability densities would be four dimen-

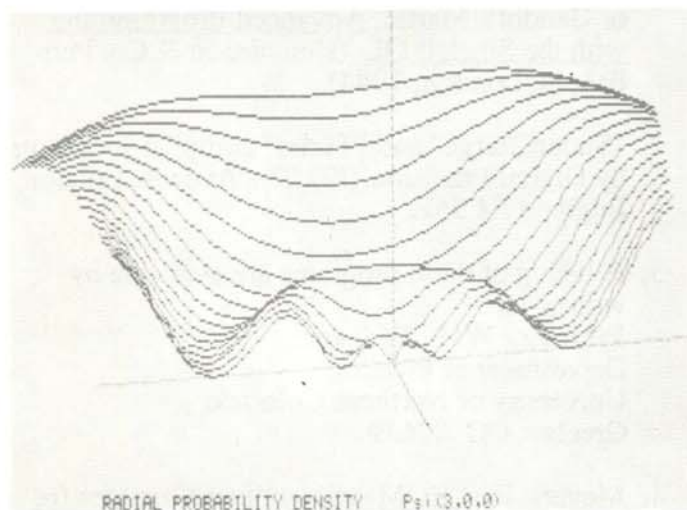


Figure 5

Radial probability density for a single electron atom, illustrating the eigenstate $\psi_{3,0,0}$, starting with a section

sional, three space dimensions and the value of the probability density making the fourth. The space dimensions have been reduced to two in this program by taking a slice along the x,y plane.

The program draws lines corresponding to lines of constant x -values. For each value of x , the value of y is incremented over its full range. The z value (the probability density) is calculated, and then a line is plotted corresponding to a line from the old position (x_1, y_1, z_1) to the new position (x_2, y_2, z_2) . The actual line is drawn from the old to the new screen positions (x_s, y_s) corresponding to the old and new x,y,z positions. This requires a transformation routine similar to that described for the deBroglie Waves sub-program. In this case, lines that would be hidden in a physical viewing from the eye location are removed using an ordinary hidden-line routine.⁷ After the values of the probabilities for values of x have been completed, the value of y is incremented, and the process is repeated for the new x value. For best appearance of the final plot, the range of x values and the increments in x and y were varied somewhat for the four different eigenstates. The $\psi_{3,0,0}$ plot includes lines representing the x,y and z axes to give a perspective to the plot. Figures 4 and 5 show two resulting probability density plots from this sub-program.

GAUSSIAN WAVE PACKETS

The third sub-program shows the propagation of a Gaussian one-dimensional free wave packet. The computational part of this program is patterned after a routine written by John Merrill⁸.

A Gaussian shape is given by the relation:

$$y(x) = \exp(-x^2 / x_0^2). \quad (3)$$

The motion of such a wavepacket can be described using a fourier transform:

$$\psi(x,t) = \sum_{k=-\infty}^{+\infty} A(k) \exp[i(kx - \omega t)] \quad (4)$$

where the amplitude of the k th component is given by:

$$A(k) = x_0 \exp(-(k - k_0)^2 x_0^2 / 2). \quad (5)$$

In these equations, x_0 is a measure of the original width of the wave packet, and k_0 is the wave number of the central component of the packet.

In the computational program, 101 components, from $k = -50$ to $+50$, are added for each value of x and t in order to approximate the continuous distribution. The real and imaginary parts of Equation 4 are calculated separately, and then the sum of their squares are taken to obtain $\psi^2(x,t)$. This value is plotted as the vertical screen coordinate. The first wave (at $t = 0$) begins centered at the origin, set near the left side of the screen. For each new time and for each value of x within a specified range, the value of each component is computed. Because of the $\exp(i(kx-wt))$ factor, each component has its own velocity. Therefore, the packet is distorted by spreading out as it moves to the right.

Since the computational program requires a long time to compute values for each wave, that program is run independently of the plotting program. The values are stored in a data file on a diskette. When the user runs the "Gaussian Wave" program shown in the listing, the data is retrieved from the disk and plotted on the screen. As the wave representing each new time is traced in white (on red), the wave for the older time is traced over in black. The effect is a viewing of the propagation and spreading of the wave packet as time passes. Since the waves for earlier times still show on the screen, one can compare the final wave to any of the earlier ones. Figure 6 shows the result of this program, with tone values changed as appropriate for better reproduction.

FURTHER DEVELOPMENTS

It is expected that this set of programs will be further developed by including additional simulations of quantum mechanical effects. Each of these can be individually developed as a complete SuperBASIC program and then merged as a procedure into the set of programs described here. A procedure for dumping any of the computer screens onto a high resolution printer is available and will be added to this set of programs. The printing routine is rather slow, and the intention is to incorporate it via multi-tasking so that the computer user can proceed to another menu choice as the screen is being printed.

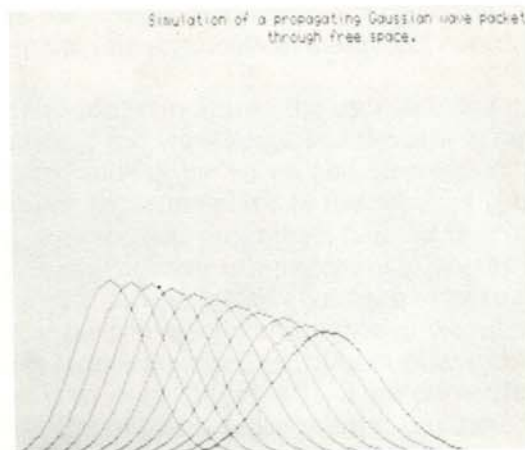


Figure 6

Gaussian wave propagation as a function of time. This figure shows 11 of the final total of 20 wave packet positions.

REFERENCES

1. The distributor of the QL Computer in the United States is A+ Computer Response, 69-B Island Street, Keene, NH 03431. Periodicals on the computer include: QL World, 79 Petty France, London, England SW1H 9ED; The QL Report, Curry Computer, PO Box 5607, Glendale, AZ 85312-5607; and Quantum Levels, PO Box 64, Jefferson, NH 03583. Information on SuperBASIC can be obtained from the instruction manual included with the computer, or from Jones, Jan QL SuperBASIC: The Definitive Handbook, (McGraw-Hill, London, 1985) or Gandoff, Martin, Advanced Programming with the Sinclair QL (Hutchinson & Co, Publishers, London, 1984).
2. "SuperCharge" and "Turbo" compiler programs by Digital Precision, 222 The Avenue, London, England E4 9SE.
3. A listing of these programs are available by writing to:
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4. Meyers, Roy E., Microcomputer Graphics for the Apple Computer, Addison Wesley, 1982, Chapter 6. This book is also available in an IBM PC version. Also see Marshall, Gary, Us-

ing Graphics on the Sinclair QL, Hutchinson & Co., Publishers, London, 1984 and Park, Chan S., Interactive Microcomputer Graphics, Addison-Wesley, Reading MA, 1985.

5. Eisberg, Robert and Resnick, Robert, Quantum Mechanics, John Wiley & sons, 1974, Table 7-2 p. 263.
6. Meyers, Roy E., op. cit., pp 152-154.
7. Meyers, Roy E., op. cit., pp 196-201.
8. Merrill, John R., Using Computers in Physics, University Press, 1976, pp 207-211.

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AN INEXPENSIVE BCD COUNTER INTERFACE FOR THE TRS-80 COLOR COMPUTER II

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ABSTRACT

For less than \$100 in parts, binary coded decimal data from a precision counter can be put into a small personal computer. This interface has been used for high precision gravity studies with a simple pendulum. The system is adaptable to other experiments where accurate counter data must be processed by a computer.

INTRODUCTION

The automated data collection interface was motivated by a desire to detect variations in the gravitational force using period measurements of a simple pendulum. Using optimization techniques, one can, with the present experimental set up, generate estimates of the pendulum period (extrapolated to zero amplitude) having a standard deviation of less than 2 microseconds. This precision is attained by a combination of factors which includes the reduction of damping by placing the pendulum in a metal vacuum chamber. The influence of magnetic forces that have been noted to affect the motion of the pendulum are also eliminated by using non-ferromagnetic materials in the pendulum construction.

The interface described in this paper was designed to transfer data from a counter to a computer, where it easily can be recorded and processed. There are three reasons why this computer/counter interface is unique. First, it is used with one of the least expensive and most widely available personal computers, the Radio Shack TRS-80 Color Computer II. Second, the interface itself is very inexpensive. The total cost of all components is nominally less than \$100. Most of the parts are locally available in the majority of university communities. These two points alone are significant, since the cost of interfacing many computers for real time analysis can be thousands of dollars. Third, since the present interface is primarily controlled by BASIC commands, it can be simply operated in a

variety of different modes. Variable clocking speeds and random reading of bit patterns are examples of the system's versatility. Moreover, this can be accomplished without the user having to sort through documentation ambiguities concerning the function of input/output ports.

The Color Computer II can be easily managed because the literature contains articles describing non-conventional use of the rear access ports. The 64K unit has the memory and speed to do much computational analysis in real time. When the speed of data taking does not require assembler generated routines¹, the extended BASIC interpreter is easy to use.

OVERVIEW OF INTERFACE FUNCTIONS

The counter, A Hewlett-Packard 5245L, provides data words in binary coded decimal (BCD) format which easily can be accommodated by the computer. Only the least significant 16 bits are presently required. They are fed in parallel to a 16 bit to 1 bit multiplexer, as shown in Figure 1. These 4 digits (16 bits) are transferred to the computer through the multiplexer via an impedance matching circuit. The most significant 4 digits do not vary in our experiment and thus can be recorded in the program as constants.

Before the data can be transferred from the counter to the computer, the computer must receive a signal from the counter indicating that the data is stable.

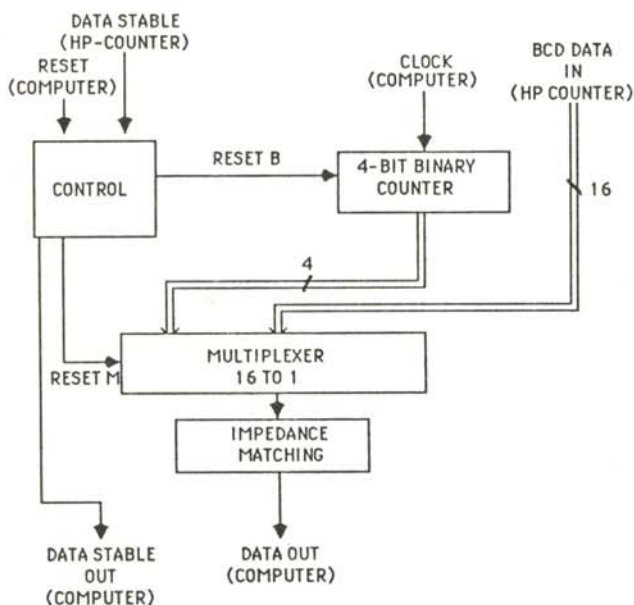


Figure 1
Logic Block Diagram

Once the data stable signal has been received, the computer serially converts the binary coded word into a form that is compatible with BASIC using a binary-to-decimal algorithm. These functions are discussed in detail in the following sections.

SECTIONS OF THE INTERFACE

The interface is broken into four sections: power supply, data transfer, pulse stretcher, and impedance matching circuit. All are assembled on a single universal circuit board which can be plugged into a Buss connector. All connections to the board from the outside world are done through the Buss strip, allowing easy modification.

POWER SUPPLY

The power supply provides stable direct current

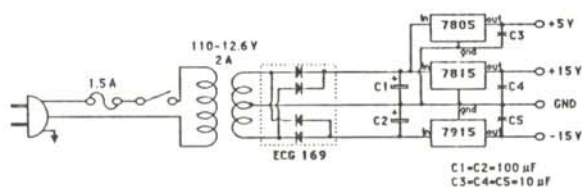


Figure 2
Power supply.

(DC) potentials for all the components used in the interface. Properly filtered, regulated voltages are generated with very few components (See Figure 2) A single center-tap transformer is used to convert the 115 VAC to 12.6 VAC. A full-wave bridge rectifier (ECG169) converts the alternating current to two channels of rippled direct current, one positive DC voltage and one negative DC voltage. Each channel is filtered by a 100 µF capacitor. The three regulators (7815, 7805, and 7915) are connected after the filter to supply regulated +15 VDC, +5 VDC, and -15VDC respectively which are required by the different integrated circuits. Bypass capacitors of 10µF are used after the regulators to aid in filtering.

DATA TRANSFER

Data transfer problems are compounded by the Color Computer's need for a serial data stream, while the counter provides a parallel data output. This compatibility problem is solved with the multiplexer 7506 shown in Figure 3. The parallel to serial conversion requires that a 4 bit binary counter (7493) provide control to the multiplexer. Since only 4 BCD digits are read, we only need a sixteen channel multiplexer.

A second compatibility problem exists between the Color Computer and the 7493 chip. The maximum output voltage from the computer for logic 1 is

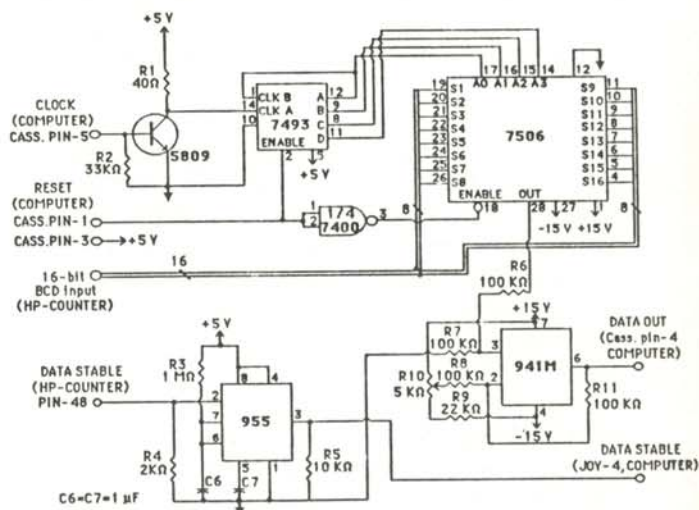


Figure 3
Interface logic diagram.

only 1.3 V. Since the 7493 is a TTL chip, this logic 1 voltage from the computer would not cause a transition from logic 0 to logic 1 in the 7493. This problem is solved by amplifying the output of the computer with a common emitter transistor circuit. A Motorola 5809 transistor is used, but many low power silicon NPN transistors with the proper base-emitter resistor should work.

As soon as the data stable signal is received from the Hewlett Packard counter, the computer resets both the 7493 counter chip and the multiplexer chip, and then begins clocking through the 16 data channels. Since the 7506 has an inverted enable/reset pin, a NAND gate is used to act as an inverter.

IMPEDANCE MATCHING

The Hewlett Packard counter output is close to -14 V for logic 0 and +15 V for logic 1. These voltages are essentially "applied" at the output of the multiplexer which behaves as an analog switch. However, the output impedance of the counter is too high for the Color Computer. With the 7506 connected directly to the computer, the output voltage does not register a negative voltage swing at all. The total swing is from .5 volts to 1.2 volts. This problem is overcome by buffering with an ECG941M operational amplifier. The 941 OPAMP is wired as shown in Figure 3. It also provides a negative offset voltage which is necessary to prevent read errors. Varying resistor R10 allows logic 1 from 0 - 4.5 V while holding logic 0 at -3.2 V. This positive-negative swing is exactly the range for which the computer data input (cassette socket pin 4) is looking.

MONO-STABLE PULSE STRETCHER

Before the computer will commence clocking through the counter's data channels, it must receive a signal from the Hewlett-Packard counter that the data is stable. This signal is read by the computer through the joystick port. It must be a 0 to 5 Volt positive edge. The data stable signal from the Hewlett-Packard counter is a negative edge from 14 to 0 Volts with such a short duration that the Color Computer can not consistently sense it. A pulse stretcher is designed to lengthen the data stable signal and invert it. The mono-stable pulse stretcher is made with an ECG955M OPAMP shown in Figure 3. The length of the output pulse is determined by the capacitors used in the 955 cir-

cuit. With the indicated capacitors, the length of the pulse is approximately one second. When the length of the pulse is changed, care must be exercised to insure that the length is less than the computational time of the reading program. If the pulse is too long, the data will be read twice without an intervening reset.

PORTS OF ACCESS

The Motorola MC6809E microprocessor is the heart of the Radio Shack Color Computer II. It is able to communicate with the outside world through a peripheral interface adapter (PIA) chip, the Motorola MC6821. This combination is used to allow maximum flexibility in external devices. There are five ports on the back of the Color Computer that are used by the interface. Two of these ports are used by the interface in an unconventional way.

The data stable signal is received by pin 4 in the right joystick socket. The command:

$$B = \text{JOYSTK}(0)$$

will cause a 0 to be placed in B when the voltage applied to this pin is less than 2 Volts. When the data stable pulse (greater than +1 Volts) is received, the value of B is brought up to 1. The control program continuously samples pin 4 (B) with an "IF THEN" loop, waiting for a data stable pulse.

To create the clocking pulse for incrementing the 7493 binary counter, cassette socket pin 5 is used. The Color Computer is designed to store data on cassette by a frequency-shift-keying (FSK) technique which varies the analog voltage at pin 5 from 17.6 mV to 1.3 V in 63 steps. Since all 63 voltages can be accessed in any order, the voltage extremes are used for logic low and logic high voltages. The following BASIC Statements produce one pulse²:

```
POKE 65312,(PEEK(65312)AND 1) OR (252)
POKE 65312,(PEEK(65312)AND 1) OR (0).
```

Cassette socket pins 1 and 3 are connected to a relay contact inside the Color Computer designed to switch the cassette motor on and off. The contact is rated at 0.5 Amps and 6 Volts, and is completely isolated from all other computer circuits. This re-

lay is used to reset the 7506 and the 7493 integrated circuits by feeding the 5 volt supply through pins 1 and 3 to the reset pins on the interface chips. The following statements close and open the relay respectively ²:

```
POKE 65313, PEEK(65313) OR 8
POKE 65313, PEEK(65313) OR 247.
```

The data measurements originating with the Hewlett-Packard counter are received (after multiplexing and buffering) by cassette socket pin 4. Using the command below, the computer will register a 1 for "A" when the input is greater than +1 Volt and a 0 for "A" when the input is less than 0 Volts:

```
A = (PEEK(&HFF20)AND1).
```

Cassette socket pin 2 is used as the reference ground.

DECIMAL CONVERSION

The Hewlett-Packard counter has BCD output that follows the pattern of 1-2-2-4 from least significant to most significant. The computer reads the least significant bit of the least significant decimal digit first and ends with the most significant bit of the most significant decimal digit. The following algorithm provides for conversion consistent with that order using the indicated DATA values.

```
10 DATA 1,2,2,4,10,20,20,40,100,
200,200,400,1000,2000,2000,4000
20 FOR J=1 TO 16:READ I(J):NEXT J
30 C=0
40 B=JOYSTK(0)
50 IF B<>0 THEN GOTO 70
60 GOTO 170
70 POKE 65313, PEEK(65313) OR 8
80 POKE 65313, PEEK(65313) AND 247
90 FOR J=1 TO 16
100 A = (PEEK(&HFF20)AND1)
110 POKE 65312,(PEEK(65312)AND 1)
OR (0)
120 POKE 65312,(PEEK(65312)AND 1)
OR (252)
130 IF A<>0 THEN C=C+1
140 NEXT J
150 PRINT C
160 END
```

REFERENCES

1. Barden, William Jr. TRS-80 Color Assembly Language Programming, Radio Shack Catalog No. 62-2077, 1983.
2. Barden, William Jr. "Color Computer from A to D.", *BYTE*, December 1981, pp 134-282.
3. Stearman, Colin J. "The Ins and Outs of the TRS-80 Color computer", *BYTE*, May 1983, pp 439-448.

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POST USE BOOK REVIEW

ELECTROMAGNETIC FIELDS, 2nd. Ed by Roald K. Wangsness
John Wiley & Sons, 1986 viii + 587

Reviewed by:

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When selecting a textbook for a year-long course in Electricity and Magnetism at the junior level, undergraduate faculty must surely consider this text. Wangsness presents the same material, in roughly the same order, as countless textbooks on this subject have done. Yet, there is an important difference between his book and the others: the derivations of important results are always clear and precise and lack the non-mathematical hand-waving that permeates so many books today.

Wangsness avoids "X-ing" as much as Einstein did. Many of the important results are stated geometrically, with an appeal to the physics and an eye towards developing a keen intuition, rather than with cumbersome mathematical tricks. For example, the entire subject of reflection and refraction of waves is developed geometrically by considering three propagation vectors which can be defined in connection with the waves and then investigating their purely geometrical properties.

The treatment given to the use of various coordinate systems in solving physics problems is excellent. Advanced vector calculus is reviewed from a practical standpoint in the first chapter. Subsequent chapters thoroughly describe and instruct the reader in how to choose and work with coordinate systems which simplify the problems. The treatment Wangsness gives to the tensor form of electromagnetism is, however, lacking quality. The tensors

themselves are discussed only enough to confuse many students. Also, the tensor form of the theory is presented with a different notation than used in many texts.

The problems given in Wangsness are the most important feature of the text. Rather than a few impossible problems, he supplies copious problems at all levels of difficulty. Short answers to half of them appear at the end of the book. These problems test the understanding of both the general principles and the mathematical details that are important in understanding Electricity and Magnetism.

ELECTROMAGNETIC FIELDS may well serve as a guide for undergraduate textbooks yet to come. For someone in the market for a good E&M text, the clarity of exposition and manner of presentation certainly makes this book worth a look.

Ken is a senior Physics major from Fremont, California and worked last summer at Oak Ridge National Laboratory in Tennessee. He is interested in studying theoretical particle physics in graduate school.