Proceedings of the Iowa Academy of Science

Volume 70 | Annual Issue Article 63

1963

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Recommended Citation

Johnson, Richard T. (1963) "Demonstration of the Transition from the Particle Approach to the Wave Approach," *Proceedings of the Iowa Academy of Science, 70(1),* 383-386.
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The results of the study suggested that the students understood the mathematical relationships and the physical situations which were represented better than was the case when they merely verified the relationships. Problems of lack of self-direction on the part of the students were soon overcome as the students performed a number of these activities.

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Demonstration of the Transition from the Particle Approach to the Wave Approach[1]

RICHARD T. JOHNSON

Abstract. This article describes a demonstration, suitable for elementary physics, to show the transition from the particle to the wave approach. Standing waves in a continuous string are approximated by particles fastened to a much lower density or "massless" string. The agreement between the continuous and discrete systems is good, and the wave approach is shown to be only another way of describing systems.

The purpose of this paper is to present a demonstration to be used at the elementary physics level to illustrate the transition from the particle approach to the wave approach as the number of particles in a system increases. In most elementary texts, the student first uses the particle approach to study such problems as blocks on inclined planes and the simple pendulum. Then in a separate section of the text, he is introduced to the wave approach and the continuous string. It is the author's feeling that this causes the student to consider the two approaches

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as completely separate and to feel that the wave approach is something special, or mystical, while in reality, they are only two different ways to describe a system, each giving different characteristics of the system.

To illustrate the transition from the particle to the wave approach, it is shown that standing waves in a continuous string can be approximated by a finite number of particles fastened to a "massless" string. Although the latter system has a finite number of particles, it behaves in a manner describable by waves. The theory behind this demonstration is given a partial treatment in Symon (1961).

Experimental Setup

Standing waves are generated by connecting three-meter continuous and loaded strings to a rotator at one end and applying a constant force of 14.7 newtons to the other end. The advantage of using a rotator is that the standing waves are three dimensional and thus do not have to be viewed from one particular direction.

When the rotator is adjusted to 16 cps, the standing waves have a wavelength of approximately two meters and an amplitude of 8 cm, which is well suited for a large classroom demonstration. The relationship connecting tension, wavelength, frequency and linear density is: wave velocity $= \lambda f = \sqrt{\frac{\tau}{\sigma}}$

Nylon string is used for the continuous and "massless" strings. The linear density of the continuous string is $\sigma = 0.134$ g/stretched cm. (Stretching force is 14.7 newtons.) The "massless" string has a linear density one-seventeenth that of the continuous string. The particles connected to the "massless" string are fishing sinkers. They are all of the same mass and are evenly spaced on the string according to the formula $h = \frac{m}{\sigma}$, where h has units of stretched centimeters when m, the mass of the particles, is in grams and σ is in grams per stretched centimeter. The unit of stretched centimeter is introduced since, when matching linear densities, it is important to allow for the stretching of the strings caused by the tension.

Equipment

The rotator is powered by a one-eighteenth horsepower, variable speed motor. The rotator itself consists of a disc connected to the motor, with the string then connected to the disc 1.25 cm off-center. It is important to take precautions so that the string does not wind up. Rock and May (1941) describe a rotator similar to that used by the author.

Since it is desired that the amplitude of the standing waves be large enough for display purposes, a constant tension cannot be obtained by fixing both ends of the string. A constant tension is obtained by fastening a 34 cm tube of diameter 1.5 cm to a board and inserting a 58 cm close-fitting solid rod into the tube. Two parallel holes, one at each end, are drilled in the rod, and the string is fastened to one end while a mass of 1.5 kilograms is connected across a pulley to the other end. Thus as the amplitude is increased, the rod is pulled through the tube, and the tension remains constant. Graphite is used for lubrication so that the rod will slide easily. Again, precautions must be taken so that the rod does not turn and wind up the string.

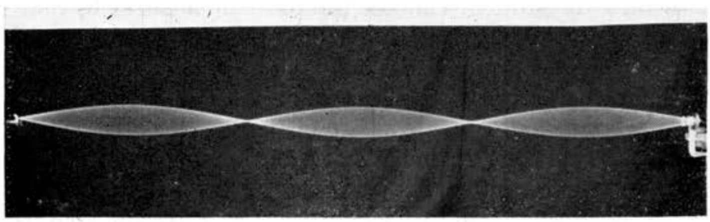

Figure 1: Continuous string.

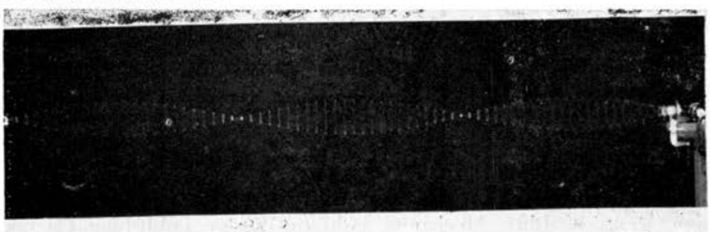

Figure 2: One particle every 4.2 cm.

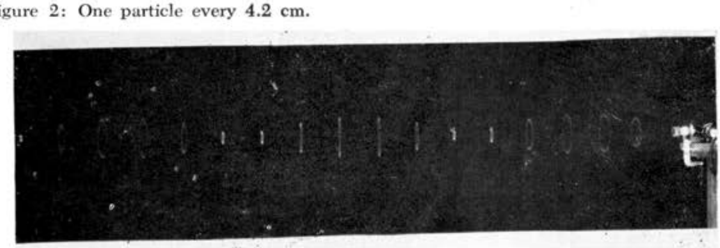

Figure 3: One particle every 17.6 cm.

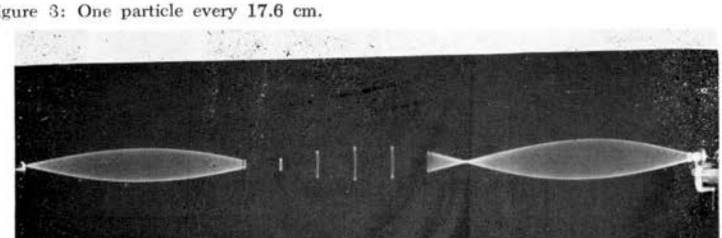

Figure 4: Particle string spliced into continuous string.

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Results

All four strings are three meters long, and the tension and linear density are the same in all four cases. The frequency is also maintained constant at 980 rpm. There is good agreement in general shape, and, within experimental error, all four agree in amplitude and wavelength. The continuous string in figure 1 is best approximated in figure 2 where the particles are only 4.2 cm apart. However, the approximation is still quite good in figure 3 where the particles are 17.6 cm apart. In figure 4, the "massless" string is spliced into the continuous string and particles attached to show the validity of the approximation.

The demonstrational value is best illustrated in figures 2 and 3, in which the student can see the individual particles and the possibility of the description of the motion of each particle. However, he can also see the advantage of the wave approach which is recognizable here as just another way of looking at the system. The student is made aware of the fact that the important thing in this type of system is not what each particle is doing, but rather, what are the characteristics of the system as a whole, such as amplitude and wavelength. It is apparent that these characteristics are easier to obtain with the wave approach, but are not impossible to obtain with the particle approach. Thus the wave approach becomes no longer mystical or special, but rather just another way of looking at systems.

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