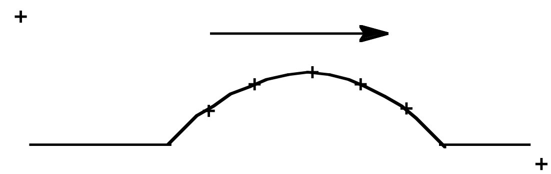
Transverse pulse interference and energy conservation

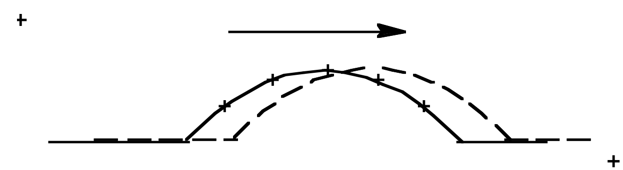
This paper is a discussion of a suggested method of presenting the energy of interfering transverse pulses. The basic physics will be discussed together with demonstrations using a snake spring. Another paper "Wave and spring techniques" has been posted that should introduce ideas on how to use a snake spring.

Establishing the motion of particles in a transverse pulse.

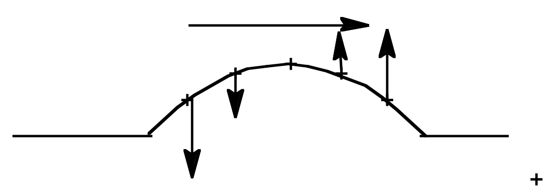
Begin by drawing a transverse pulse moving in a particular direction and ask the students to tell which way the particles are moving at assorted places on the pulse. Stress that they are moving transversely, hence only "up or down".



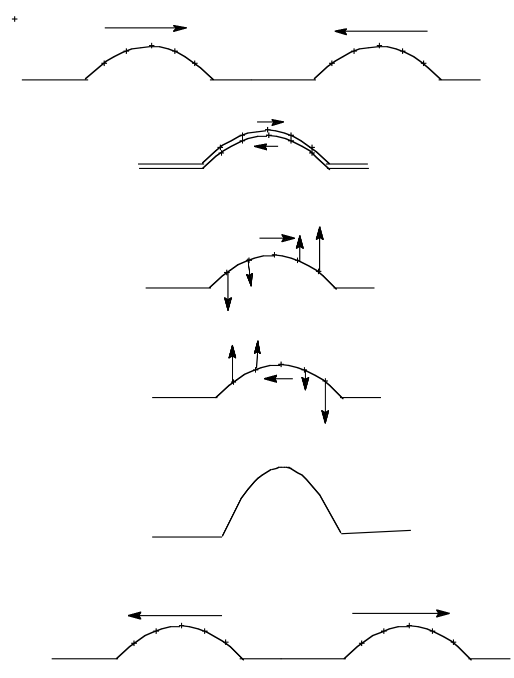
Do not show them the 2nd illustration on the right until they have given answers. The key is to diagram where the pulse will be a short time later and then identify which way the particles must have moved in order to arrive at the place illustrated with dashes on the right.



Hopefully it will be obvious that the 3rd illustration on the right is the correct description of the direction the particles must be moving. There may be a problem with the point at the peak of the pulse but if the later time for the dashed pulse were very small, there would be little or no motion of the point at the top



The illustration on the right shows two pulses of the exact same shape and phase approaching one another. The 2nd illustration shows the instant they are on top of one another and will interfere to form a single displacement of the spring. The 3rd and 4th illustrations are separations of each pulse to show which way the individual particles are moving as they interfere. Using the principle of superposition we will add the individual displacements together to find the <u>shape</u> of the combined pulses as well as using the vector sum of the velocity vectors to find the <u>velocity</u> of the individual particles. It can be seen that since the displacements are in the same direction, the displacement of the combined pulses will produce twice the displacement of the combined pulse. However, sine the velocity vectors are in the opposite direction, at the instant of combination, each part of the spring will not be in motion. The final illustration shows the two individual pulses continuing on in their original direction.

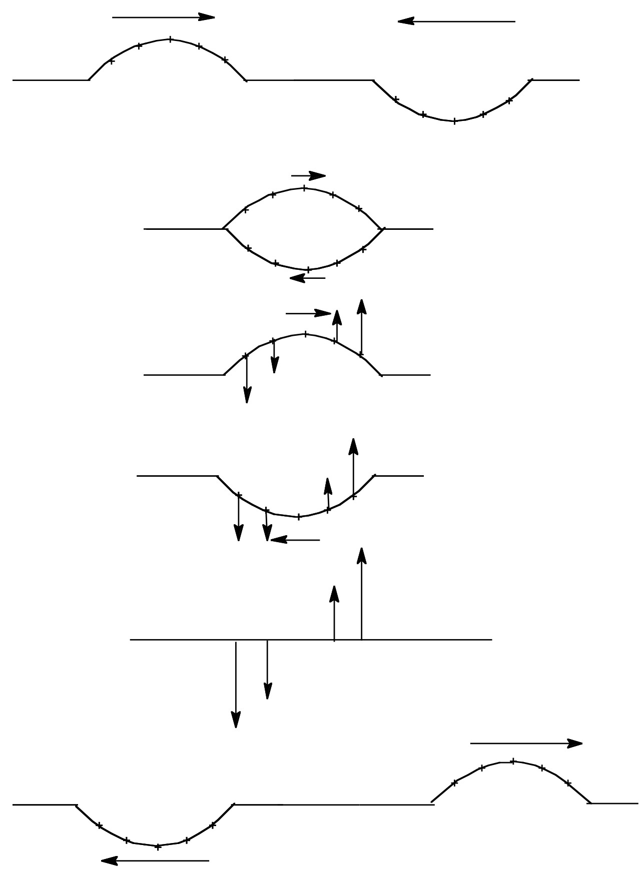


What happens to the energy of the original pulses when they combine and interfere?

Rather than discuss the velocity and displacement of two equal pulses moving in opposite direction as done above, it might be better to discuss what happens if two identical pulses but with opposite phase interfere. It could perhaps be demonstrated or simply be discussed with a question like, what will happen to the spring if two identical pulses of opposite phase interfere? The students will probably guess that the spring will become flat. Then you ask: What happened to the energy? If, as most students, they have difficulty with this you could suggest that energy is not conserved with waves. If they don't laugh, you will have to reconsider your previous teaching. How energy is conserved will be explained below.

The first illustration shows equal pulses of opposite phase approaching one another. The 2nd illustration shows them on top of one another and the 3rd and 4th illustrations separate them so the velocities of each pulse can be examined. Although the displacements are in the opposite direction and will add to zero, the velocities are in the same direction and will combine to produce twice the velocity of each. The 5th illustration shows the flat spring but its parts are moving as shown with twice the original velocity. The final illustration shows the original pulses moving on in their original direction. To make an intuitive discussion of the total energy involved, suggest that each pulse, no matter its phase, has one unit of potential energy (displacement of the spring) and one unit of kinetic energy (motion of parts.).

For the same phase case discussed on the previous page, two units of kinetic energy vanish and all 4 units are potential. For the opposite phase case illustrated here on the right, all the potential energy has vanished but there are 4 units of kinetic energy.

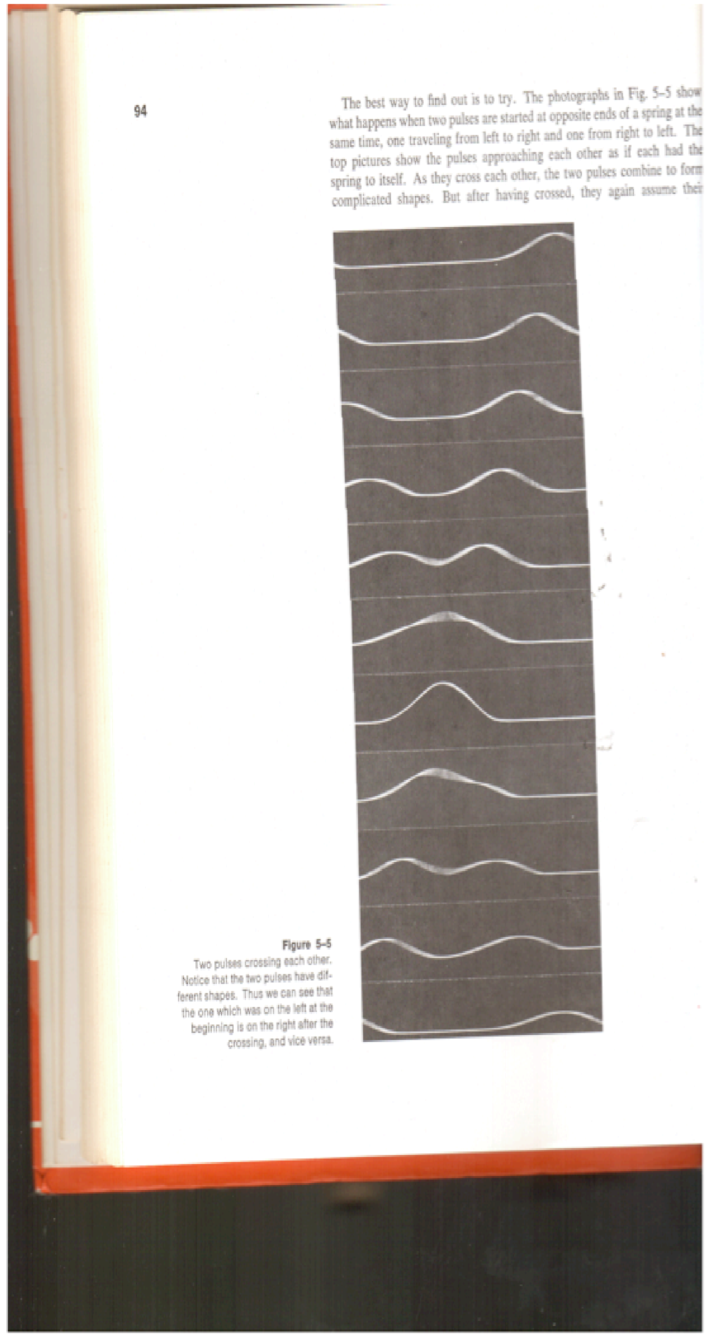


More details can be introduced if the students know that a stretched spring with force constant, k, will have potential energy $U = \frac{1}{2} kx^2$ (x is the distance stretched) and the kinetic energy of the particles will be $\frac{1}{2} m v^2$. With this it will be easy to argue that with no kinetic energy, twice the displacement will lead to 4 times the potential energy and with no potential energy, twice the velocity will lead to 4 times the kinetic energy.

The following two pages are taken from the PSSC text**: "PHYSICS".** This was a very popular text used in the previous century that was written collectively by many physicists and physics teachers called the "Physical Science Study Committee." Look around in your school and you might find a copy of this excellent text. They can still be found on the web.

The illustration shown on the right below is a photograph of successive images of two pulses of the same phase launched in opposite directions on the same spring. The shutter speed was rather slow so that a blurring of the images would show the motion of parts of the spring.

Hopefully the images are good enough that you can notice that all frames have some blur except for the individual frame seven down from the top. This is where the two equal pulses come exactly together and all the velocity vectors cancel. Here the image is quite sharp. All the energy is in the displacement of the spring, potential energy, and since there is no velocity of the particles, the image is sharp.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The best way to find out is to try. The photographs in Fig. 5–5 show what happens when two pulses are started at opposite ends of a spring at the same time, one traveling from left to right and one from right to left. The top pictures show the pulses approaching each other as if each had the spring to itself. As they cross each other, the two pulses combine to form complicated shapes. But after having crossed, they again assume thei

Figure 5–5
Two pulses crossing each other. Notice that the two pulses have different shapes. Thus we can see that the one which was on the left at the beginning is on the right after the crossing, and vice versa.

On the next page there will be a similar photograph only this time of two almost equal pulses of the opposite phase.

Once again the photograph to the right below is taken from the PSSC text. These photographs were so popular that many other physics texts obtained the rights to use them in their texts as well. Search around and you may be able to find better examples of these photographs in other texts. The PSSC text also shows many other photographs of pulses launched on springs of different mass, with fixed and free ends, etc. Good still photographs have an advantage over videos since individual frames can be studied.

Hopefully the resolution of the photograph on the right is good enough to show that every image is somewhat blurred, indicating that at no time do the approaching pulses of the opposite phase have parts that are not moving.

Of particular interest is the frame 5 down from the top. Here the spring is almost flat but is quite blurry. This is because the velocity vectors add to form a maximum giving maximum kinetic energy but little potential energy.

It is interesting to anticipate what these velocity vectors will produce in the next frame below and notice that the next frame shows the result of the pulses crossing over one another and continuing on in their original direction and phase as subsequent frames show.

Interference in two and three dimensions

It should be appreciated that although these discussions have been only of pulses on a single spring (essentially one dimensional) when interference patterns are extended to two dimensions (on the surface of a pond or ripple tank) or even to three dimensions (sound from loudspeakers in space) energy will always be conserved. When there are nodes and antinodes, the energy that might appear to be lost in the nodes will be transferred to the antinodes.

Naturally this also works for electromagnetic waves. Radio stations can use two transmitting towers to strategically place an antinode over a desired target and allow less energy to go where it is not desired. Often students may notice that lenses on glasses and optical instruments have been coated. (With binoculars they often show purple reflections from their surface.) These thin films are carefully designed to produce nodes upon reflection, which will send more energy through the lens.