

WAVE EQUATION - WAVE SPEED AND STANDING WAVES

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Any function of form $f = f(z \pm vt)$ (for a constant v) is a solution of the wave equation

$$\frac{\partial^2 f}{\partial z^2} = \frac{1}{v^2} \frac{\partial^2 f}{\partial t^2} \quad (1)$$

Once we specify f , we can plot it as a function of z for a fixed value of t , say t_1 . This shows a snapshot of the wave at a particular time. If we then plot f as a function of z at some later time t_2 , the wave has the same shape but is shifted along the z axis. A point at which f has the value $f_1 \equiv f(z_1 - vt_1)$ will have moved to a position z_2 where $z_2 - vt_2 = z_1 - vt_1$. In other words, that particular point on the wave moves from z_1 to z_2 in a time $t_2 - t_1$, and must be moving with speed

$$\frac{z_2 - z_1}{t_2 - t_1} = \frac{v(t_2 - t_1)}{t_2 - t_1} = v \quad (2)$$

Thus v is the speed of the wave. If $z_2 > z_1$, then $v > 0$ and the wave moves towards increasing z . If $z_2 < z_1$, then $v < 0$ and the wave moves towards decreasing z .

Since the wave equation is linear, any linear combination of solutions is also a solution, so we can add together waves with equal and opposite speeds. For example, if we have two sine waves with equal and opposite speeds, we can add them together to get

$$f(z, t) = \sin(k(z - vt)) + \sin(k(z + vt)) = \sin kz \cos kvt - \cos kz \sin kvt + \sin kz \cos kvt + \cos kz \sin kvt \quad (3)$$

$$= 2 \sin kz \cos kvt \quad (4)$$

where k is a constant.

The latter form is not a function of form $f(z \pm vt)$ but as it's a sum of two functions of this type, it is still a solution of the wave equation. In fact, it represents a standing wave, that is, a wave which doesn't travel along the z axis, but rather oscillates in place. We can see this since for all points

$z_n = n\pi/k$ where n is an integer, $f(z_n, t) = 0$ for all times t . For all times $t_n = (2n + 1)\pi/2kv$, $f(z, t_n) = 0$ for all positions, so the wave becomes a flat line. In between these times, the wave oscillates between its maximum and minimum heights of $\pm 2 \sin kz$.

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