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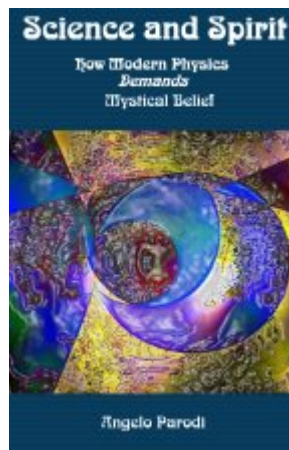
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Science And Spirit



By Angelo Parodi

The Quantum Well

A consequence of this quantum mechanical nature of the world is that particles can appear in places where they have no right to be (from an ordinary, common sense [classical] point of view). For a real-world example of this phenomena, consider the so-called quantum-well problem:

Let's begin by examining how objects behave in the world of classical mechanics.

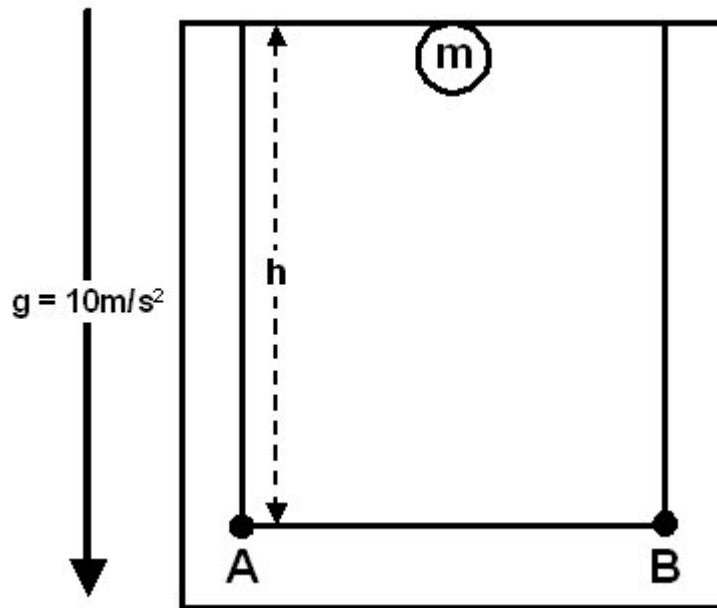
An object can store energy as the result of its position. For example, the heavy ram of a pile driver stores energy when held at an elevated position. This

stored energy of position is referred to as gravitational potential energy. In general, gravitational potential energy is the energy stored in an object as the result of its vertical position (i.e., height). This energy is stored due to the gravitational attraction between the Earth and the object. The gravitational potential energy of the ram in a pile driver is dependent on two variables—the mass of the ram and the height to which it is raised. There is a direct correlation between gravitational potential energy and the mass of an object: more massive objects have greater gravitational potential energy. There is also a direct relation between gravitational potential energy and the height to which the object is raised: the higher an object is elevated, the greater the gravitational potential energy.

These relationships are expressed by the following equation:

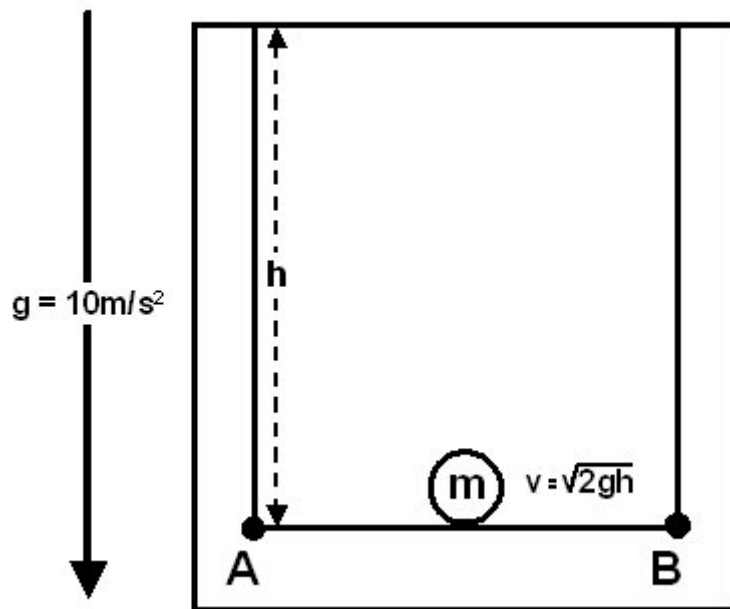
$$E_p^{\text{grav}} = \text{mass} * g * \text{height}$$

where g is a constant representing the gravitational attraction of the earth.



Suppose we have a well, as shown in Figure 5. We begin by holding a ball so that its upper surface is precisely aligned with the top edge of the well. Using classical mechanics, the ball has a certain amount of potential energy, given by the mass of the ball, times the height, times the gravitational constant, as previously described.

If we release the ball, it will fall into the well, gaining velocity as it goes.



When it reaches the bottom (Figure 6), it will (for our purposes) have no more potential energy, however, it will then have kinetic energy as a result of its velocity. This will be given by the formula:

$$E_k = (1/2)mv^2,$$

where v is the velocity the ball has attained by the time it reaches the bottom of the well. Since no energy was added (i.e., we didn't *throw* the ball downward), this will be equal to the original potential energy. We can figure out the velocity if we know the original height (h)—it works out to:

$$\sqrt{2gh}$$

(As an aside, note that the mass, m has dropped out of the equation. This is why Galileo's famous experiment, in which he dropped two different masses from the leaning tower of Pisa, proved that two different weights would fall at the same rate.)

Ignoring friction, the ball will then bounce, reversing direction, and rise back to its initial position, as shown in Figure 5. So long as no additional energy is added to the system, the ball can never get out of the well. This is because rising above the height of h would require more energy than it started with. Thus, using classical mechanics, the probability of the ball ever finding itself beyond the area delineated by points A and B is precisely zero.

We can, in various ways, set up a similar situation using an electron instead of a ball. In this case (known as the quantum-well problem), however, the result is quite different. Because the laws of classical physics don't apply, we have to use the rules of Quantum Mechanics instead. Quantum Theory says there is a

definite non-zero probability our electron will find itself outside of the well. In fact, it's position could be anywhere out to infinity.

This happens to have been one of the first problems I had to deal with right out of college, working at Digital Equipment Corporation's Advanced Semiconductor Development Lab in Hudson, Massachusetts. We were developing the DEC Alpha chip (at that time, the fastest microprocessor in the world), and as it turns out, this exact phenomenon started showing up in the ultra thin-film transistors being used in the high-speed circuits. As you can easily imagine, a misplaced electron translates into a misplaced bit, which can wreak havoc in the world of digital logic. What we discovered after many hours of reviewing our basic architecture was that the inexplicable errors were, in fact, due to that pesky electron tunneling phenomenon. So, the answer is: "yes, these effects are definitely real." This, however, is by no means the strangest phenomenon predicted by Quantum Theory.