Work and kinetic energy

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We point to a problem with the generally accepted concept that work $W = \int F \cdot dx$ transfers kinetic energy $KE = (1/2)mv^2$. We show that with exactly the same amount of work, done through a two-disk pulley or a lever, different amounts of kinetic energy can be imparted to objects of different masses. We do this without violating the laws of classical mechanics or the work-kinetic energy theorem $W = \Delta KE$.

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We demonstrate that with the same constant force $\boldsymbol{F} = d\mathbf{p}/dt$, applied through the same distance $\boldsymbol{x}$, through two-disk pulleys [1], it is possible to impart different amounts of kinetic energy $KE = (1/2)mv^2$ to objects of different masses. This, without violating Newton's laws of motion, or the work-kinetic energy theorem $W = \Delta KE$ [2].

Three pulleys, with two disks of radii r and $2r$, are mounted on vertical axles about which they can rotate freely; the axles are anchored on top of a frictionless air table. A block of mass m, $2m$, or $m/2$, is attached to a cord wrapped around a disk of each pulley; another cord, where a constant force $\boldsymbol{F}$ is applied, is wrapped around the other disk, or the same disk, in the case of the block of mass m. This is illustrated in the following figure.

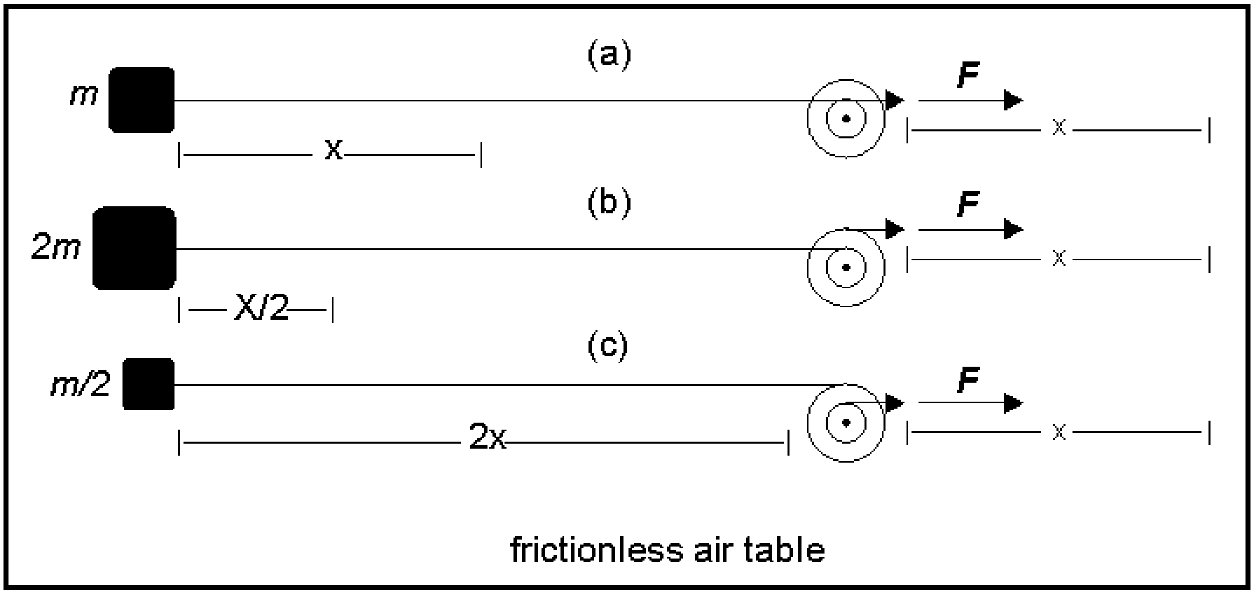

FIG. A person exerts a constant force ***F*** through the distance ***x*** on the loose end of the cord of each pulley, in the direction shown in the figure. Simultaneously, by their respective geometric constraints, the block of mass m is displaced a distance ***x***; the block of mass $2m$ is displaced a distance ***x***/2; and, the block of mass $m/2$ is displaced a distance 2***x***, as shown in the figure.

To calculate the kinetic energy of the blocks, for simplicity, as customary, we assume the pulleys and cords have negligible mass, the cords are unstretchable, and there is no friction. Since, according to Newton's second law, force $\mathbf{F} = d\mathbf{p}/dt = m\mathbf{a} = 2m(\mathbf{a}/2) = (m/2)2\mathbf{a}$ [3], the accelerations of the blocks are as we have just expressed, and since we know their corresponding displacements, according to the work-kinetic energy theorem, the kinetic energies of the blocks are, respectively,

$$KE_{(a)} = max, \quad (1)$$

$$KE_{(b)} = 2m(a/2)(x/2) = (1/2)max, \quad (2)$$

and

$$KE_{(c)} = (m/2)(2a)(2x) = 2max, \quad (3)$$

which are not equal. The traditional solution of this problem, which asserts that the kinetic energies of the three blocks are equal, violates Newton's second law and the work-kinetic-energy theorem.

The above example shows that two-disk pulleys make possible to change the distance through which a given force $\boldsymbol{F} = m\boldsymbol{a}$ is applied on an object; since work $W = F \cdot x = \Delta KE$, the same force, exerted through a two-disk pulley, can produce different amounts of kinetic energy on objects of different masses. But, evidently, pulleys do not produce kinetic energy; the person or agent that exerts the force on the pulley produces the kinetic energy. This example demonstrates that work does not transfer kinetic energy, because, if that were true, every time that a person or other agent exerts the same constant force $\boldsymbol{F}$ though the same distance $\boldsymbol{x}$, equal amounts of kinetic energy would be transferred. The confusion between work and kinetic energy seems to have originated in about 1829, when Gaspard-Gustave de Coriolis [4], a French mathematician and engineer, defined *work* in the same terms as kinetic energy. If work had been defined, perhaps more logically, as force · time, it would have been clear from the beginning that work did not transfer kinetic energy.

Since work does not transfer kinetic energy, it is convenient to clarify the relation between energy and work: Energy is indispensable to do work or any activity: only energy transformations (due to chemical or nuclear reactions) produce the forces required to carry them out. But energy is always conserved; thus, the amount of energy existing before and after work, or any activity, is accomplished, is the same. This knowledge is conceptually important; it means that *work* is not a form of energy, and disproves the first law of thermodynamics $dE = dQ - dW$.

The results we have obtained, which were corroborated by experiment, do not violate the law of conservation of energy, which is valid only in closed, isolated systems; rather, these results suggest that we are not in such a system. The foregoing is part of a theory, currently in preparation, based on the premise that to do *work*, or for any activity, energy in some form is always required.

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[1] Cutnell, John D. and Johnson, Kenneth W., *Physics* ((John Wiley & Sons, Inc., New York 2001), p. 253.

[2] Giancoli D. C., *Physics for Scientists and Engineers* (Prentice Hall, Englewood Cliffs, NJ) 1989), p. 148.

[3] Halliday D., Resnick R., and Walker J., *Fundamentals of Physics* (John Wiley & Sons, Inc., New York 2001), p. 22.

[4] G-G Coriolis (1832). *"Sur le principe des forces vives dans les mouvements relatifs des machines". J. De l'Ecole royale polytechnique* **13**: 268–302.