The Point-Particle System

Bruce Sherwood
Ruth Chabay

Department of Physics
North Carolina State University

Originally presented at a meeting of the
American Association of Physics Teachers
San Antonio, August 1999

Supported in part by NSF grant #DUE-9554843

The True Energy Equation

$$\Delta E_{sys} = \sum_i \left[\int \vec{F}_i \bullet d\vec{r}_i \right] + Q + \ldots$$

where

$$E_{sys} = K_{trans} + K_{vib} + K_{rot} + U_{grav} + U_{chem} + \ldots$$

$W = \sum_i \left[\int \vec{F}_i \bullet d\vec{r}_i \right]$ (true work; *individual* forces)

The Pseudowork-Energy Equation

Since $M\dfrac{d\vec{v}_{cm}}{dt} = \vec{F}_{net}$ for a multiparticle system,

$$\int \vec{F}_{net} \bullet d\vec{r}_{cm} = \int M\frac{d\vec{v}_{cm}}{dt} \bullet d\vec{r}_{cm} = M\int d\vec{v}_{cm} \bullet \frac{d\vec{r}_{cm}}{dt}$$

$$\int \vec{F}_{net} \bullet d\vec{r}_{cm} = M\int \vec{v}_{cm} \bullet d\vec{v}_{cm} = \Delta\left[\frac{1}{2}Mv_{cm}^{2}\right]$$

$\Delta K_{trans} = \int \vec{F}_{net} \bullet d\vec{r}_{cm}$ (pseudowork; *net* force)

where

$$K_{trans} = \frac{1}{2}Mv_{cm}^{2}$$

The Pseudowork-Energy Equation

$$\Delta K_{trans} = \int \vec{F}_{net} \bullet d\vec{r}_{cm}$$

Compare with the True Energy Equation

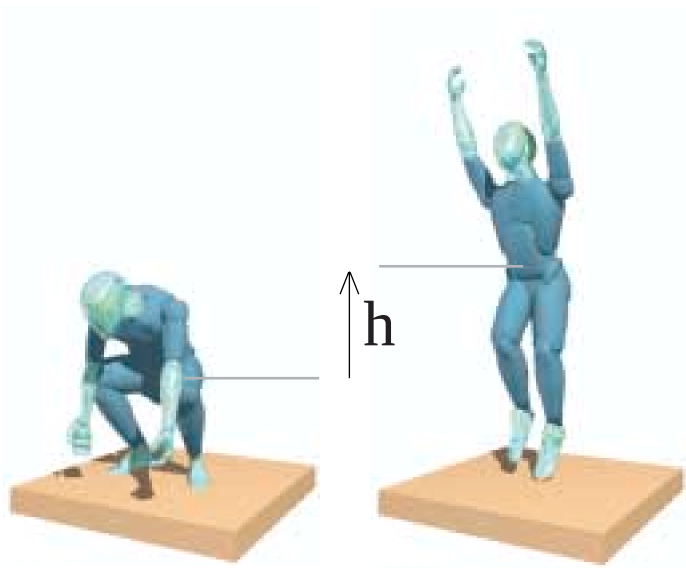
$$\Delta E_{sys} = \sum_{i} [\int \vec{F}_i \bullet d\vec{r}_i] + Q + ...$$

where

$$E_{sys} = K_{trans} + K_{vib} + K_{rot} + U_{grav} + U_{chem} + ...$$

$W = \sum_{i} [\int \vec{F}_i \bullet d\vec{r}_i]$ (true work; *individual* forces)

Example: Jumping Up



Pseudowork-energy equation

$$\Delta K_{trans} = (N - Mg)h$$

True energy equation

$$\Delta K_{trans} + \Delta K_{other} + \Delta E_{therm} + \Delta E_{chem} = -Mgh$$

Pseudowork in Introductory Textbooks

- Omitted from most introductory textbooks.
- This leads to incorrect treatments of energy, including situations involving sliding friction.

References:

Sherwood, B. A. (1983). Pseudowork and real work. *American Journal of Physics* **51**, 597-602.

Sherwood, B. A., & Bernard, W. H. (1984). Work and heat transfer in the presence of sliding friction. *American Journal of Physics* **52**, 1001-1007.

Problems Teaching about Pseudowork

- Attempts to teach pseudowork had limited success in the 1970’s and early 1980’s at the University of Illinois, and in 1997 at Carnegie Mellon.

- Additional new concepts; added burden.

- Students find it difficult to distinguish between two similar equations (the pseudowork-energy equation and the true energy equation).

- Students often fail to invoke the pseudowork-energy equation.

- Considering the poor results, we considered dropping the topic despite its importance.

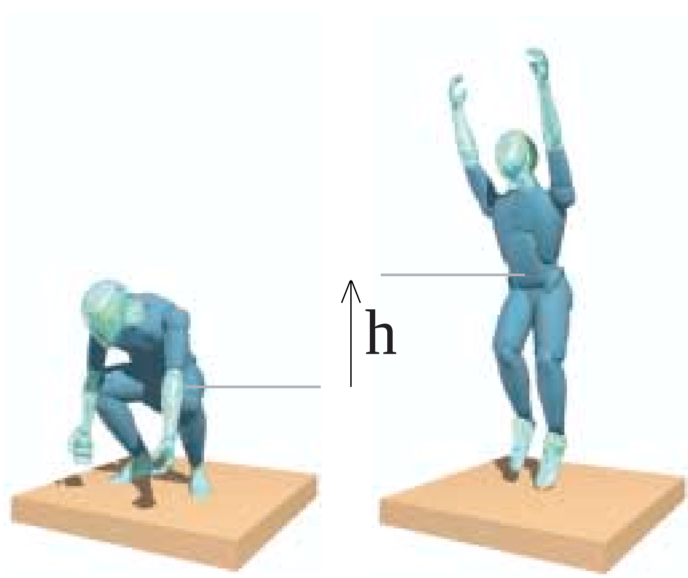
New Approach: The Point-Particle System

Consider a point particle:

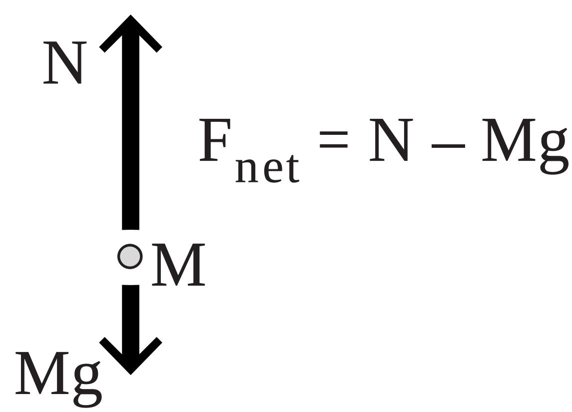
- has total mass of real system
- located at center of mass of real system
- subjected to same forces as real system

The true energy equation for this point-particle system is identical to the pseudowork-energy equation for the real system.

Real system



Point-particle system



$$\Delta K_{trans} = (N - Mg)h$$

This is also ΔK_{trans} for the real system.

Pedagogical Advantages

- Striking visual distinction between two systems, rather than fine distinction between two equations.

- Students more likely to invoke the point-particle equation and to use it correctly.

- No really new concepts; familiar results for a point particle. One concept applied twice rather than two different concepts.

A Student Reflection

I’m surprised that most physics courses avoid the topics covered in this chapter (nonrigid systems and the energy analysis of systems involving friction) when they can be dealt with as straightforwardly as they are here. Typically friction is described as a "nonconservative force" and left at that.

I’ve always realized that most physics courses operate in a dream world of frictionless pulleys and massless strings because many real-world effects can’t easily be calculated analytically. This, however, is the first time I’ve seen a topic which can be dealt with using basic principles and simple algebra (meaning no iterative calculations) but which isn’t covered in physics textbooks (at least not in MY high school physics textbook).

D.S.

For More Information

See the textbook *Matter & Interactions: Modern Mechanics* (vol. 1), Ruth Chabay and Bruce Sherwood, Wiley 2002, Chapter 7, “Multiparticle Systems.”

Web site:
http://www4.ncsu.edu/~rwchabay/mi