Tracing the "Flow" of Energy in *Force, Motion, and Energy*

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We all have a sense of what energy is, but most of us would be hard-pressed to define it in words. The old phrase "the ability to do work" – while often quoted – is certainly not definitive, nor is it satisfying. Is energy an "ability"? Does all energy "do work"?

To begin the discussion of energy in Chapter 6 of *FM&E*, we acknowledge the difficulty in defining this concept by offering an *operational* definition for energy. We point out that changes never occur in isolation; every change is accompanied by some other change. We then say that any change that is accompanied by a change in temperature is a *change in energy,* and that a change in temperature indicates a change in a particular type of energy, which we call *thermal energy* (Figure A). This provides the starting point for our study of energy and leads to the investigations in the remainder of Chapter 6.

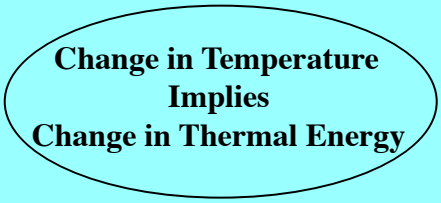

Figure A - Operational Definition
A change in temperature is used to operationally define a change in thermal energy.

By the time students reach Chapter 7 they are familiar with changes in thermal energy, heats of fusion and vaporization, and the specific heats of various substances. This last item allows students to determine the change in thermal energy of the apparatus used in Experiment 7.1, Heating Produced by a Slowly Falling Object. Since the thermal energy of the apparatus increases, it must be accompanied by another energy change. Student data from Experiment 7.1 and evidence presented in the reading section that follows show that the change in thermal energy is proportional to both the weight of the falling object and the distance it falls. Since both falling and weight involve gravity, this evidence leads us to define a new form of energy – *gravitational potential energy* (Figure B). We say that the increase in thermal energy of the apparatus is accompanied by a decrease in the gravitational potential energy of the falling object. This definition comes about not from the declarative statement of a "fact" in the text, but rather through careful preparation, accurate measurements, and the analysis of quantitative data obtained by the class.

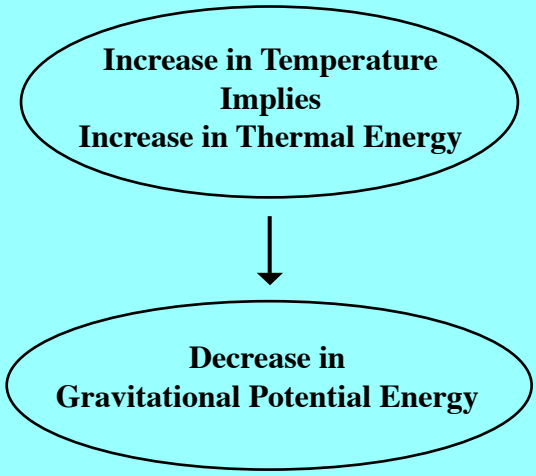

Figure B - Gravitational Potential Energy
An increase in thermal energy is used to define a decrease in gravitational potential energy.

Section 7.3, Elastic Potential Energy, presents evidence that there must be a change in energy associated with the contraction of a stretched spring since it also causes an increase in the thermal energy of the apparatus used in Experiment 7.1. We define this change as a decrease in the *elastic potential energy* of the spring (Figure C on the next page). Section 7.4, Kinetic Energy, similarly shows that there must be a change in energy associated with a change in the speed of a spinning wheel since a brake used to stop the spinning wheel heats up. We define this change as a decrease in the *kinetic energy* of the wheel. Like the change in gravitational potential energy, the studied changes in elastic potential energy and kinetic energy result in thermal energy changes.

Section 7.7 describes two experimental setups. The first allows the study of transformations between gravitational potential energy and kinetic energy. The second involves the study of transformations between elastic potential energy and kinetic energy. Transformations between elastic potential energy and gravitational potential energy are addressed by means of a question (#18) at the end of Section 7.7. They can be shown with a simple demonstration of a mass moving up and down on a spring (and analyzed at the

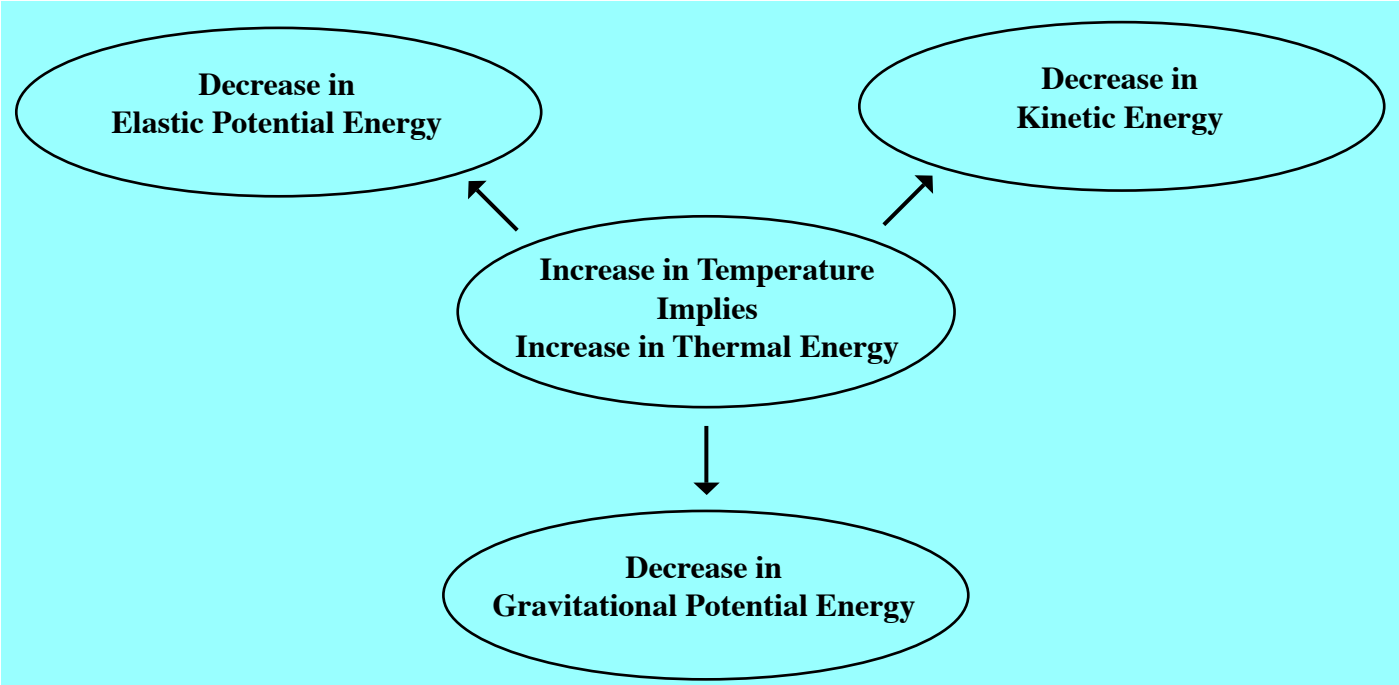

Figure C - Elastic Potential Energy and Kinetic Energy
Increases in thermal energy are also used to define decreases in elastic potential energy and kinetic energy.

top and bottom of the motion).

Figure D summarizes the energy transformations that have been studied. Note the differences between this diagram and those that come before it. The previous three diagrams have shown how different forms of

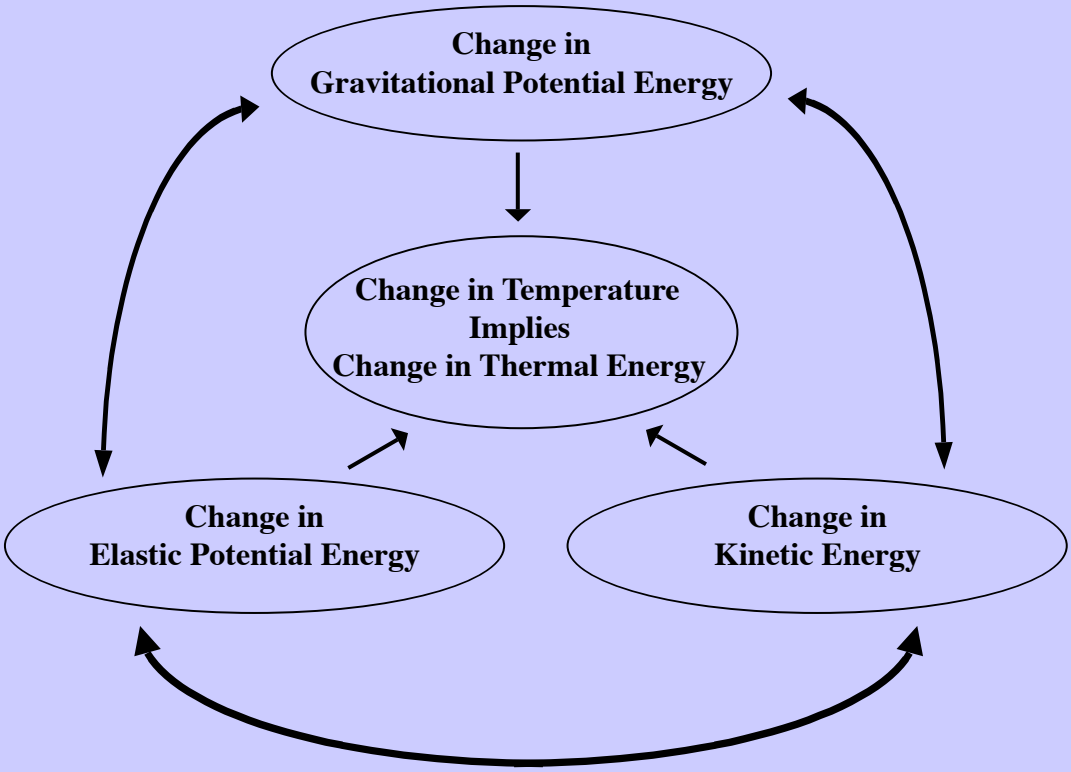

Figure D - Energy Transformations
A summary of the energy transformations studied in *FM&E*. Note that the transformation between elastic potential energy and gravitational potential energy, while treated as a problem in the text, but can be shown with a simple teacher demonstration.

energy are defined in *Force, Motion, and Energy*; they are defined in reference to thermal energy, which in turn is based on a measurable quantity – a change in temperature. Consequently, each of the arrows in Figures A through C could be read as "is used to define," as in "a change in thermal energy *is used to define* a change in gravitational potential energy."

Figure D, however, does not deal with definitions. It describes the connections among the energy forms that are studied in *FM&E*. Keep in mind, though, that Figure D does not include all of the possible transformations among these energy forms. For example, the one-way arrows at the center of the diagram describe what has been studied, but they are not meant to imply that transformations never take place *from* thermal energy *to* some other form. As a learning extension, you might ask students to describe how thermal energy could be used to cause a change in gravitational potential, elastic potential, or kinetic energy. It will also be obvious to those students who have used *Introductory Physical Science* that there is another item missing from the diagram – the change in thermal energy associated with chemical reactions.

The experiments in *FM&E* Chapters 6 and 7 provide rigorous, quantitative data leading to the generalization that energy is conserved. They provide an experimental basis for understanding energy conservation rather than having "energy is conserved" simply appear as a statement that students must read and accept. And they provide a deeper and richer understanding of energy than the incomplete and incorrect "ability to do work" definition.