

Reconciling Biological and Physics Energy Concepts

Physics calculates that the work done in raising a weight and lowering it back down to be zero, but we know that our bodies must burn energy doing that. So why the difference?

The simple answer is that our bodies are extremely efficient about utilizing and storing food energy, but quite inefficient at doing mechanical work and unable to store significant amounts of mechanical or electrical energy. A kangaroo's hind legs, however, are very good at working like springs - storing mechanical energy when landing to be reused on the next leap. We do that with a Pogo Stick. A clam can lock its shell together without getting tired.

Heat is a form of energy, but a temperature difference is needed to convert heat energy to mechanical energy. On a very hot day, we sweat to keep from overheating - without water to sweat, we quickly die. A steam engine makes hot steam that pushes a piston and exhausts the steam to a lower temperature. Without a lower temperature than the boiler steam, it can do no work. When we use our muscles to do mechanical work, they get hot and need to be cooled by the outside air or by losing moisture through panting like a dog or sweating.

When we eat more than our immediate needs, we store the excess food energy as fat to be used later as needed. For each 9 food calories extra, we store 1 g of fat. That is a standard conversion factor used in food calculations.

A typical person doing typical activities will burn about 2000 calories per day, a bit more for men and a bit less for women because of size and muscle proportion.

Food can be loosely categorized as sugars, fats, and proteins. We will build molecular models of these later in the course. Sugars and proteins both have about 4 food calories per gram and fats have 9 calories per gram as noted above. What about carbohydrates? Our bodies digest carbohydrates into sugars with great ease so carbohydrates are essentially sugars with 4 calories per gram. Cellulose that trees are built from is also made sugars, but we cannot undo the bonding in cellulose to free its sugars so we get no food calories from eating wood and grass. Animals lack the necessary enzymes to break down cellulose but termites and herbivores get help from microbes living in their gut.

To store excess food energy, our bodies can convert sugars to fats and back again fairly efficiently. So we assume perfect conversion efficiency, eating 1000 food calories per day more than we need will cause our bodies to store $1000 \text{ food calories} / 9 \text{ food calories per gram} = 111 \text{ g of fat}$. If we do that for 9 days in a row, we will have stored about 1 kg of additional fat.

It is more realistic to imagine that we might eat an extra 100 food calories per day and therefore gain 1 kg every 90 days or 10 kg in about 3 years. No wonder people gain weight as they age if food is not scarce and physical activity is less demanding.

An athlete in training may burn an extra 1000, 2000, or even 3000 more food calories per day, but unless that involves hauling masses up a hill and leaving them there, that energy is used to maintain or build muscles. In fact a runner accelerates burning extra mechanical energy and gets it back when slowing down. Running uses energy to friction in joints, reloading and repairing muscles, ground deformation, and air resistance.

When a 100 kg person hikes up 1000 m to the top of mountain, nearly 1 million joules of mechanical energy are expended. That is equivalent to about 240 food calories. Upon descending that energy is returned so that no net mechanical energy is used for the round trip. Yet we have used perhaps an extra 2000 food calories making the trip because our bodies are not perfectly efficient and cannot store that energy received during the descent. Going downhill, however, is definitely easier than going uphill, that is the benefit we get from gravity. Going down about a 10% grade is easiest. A steeper descent forces our muscles to keep us from going too fast and burns additional energy. Jumping off a cliff allows us to descend with no effort, but all our energy is converted to a mess at the bottom.

Upon descent, a roller-coaster stores its gravitational energy as kinetic energy that can be used to go up another rise. A Pogo stick stores energy in a spring. A hybrid stores some energy in a large battery so that its average efficiency is improved. The extra weight of the battery, however, increases its rolling friction losing energy to heating the road and tires so an engineering compromise is required.

In the mountains are two reservoirs, Wishon and Courtright with Wishon nearby, but about 1500 m lower in altitude. Pipes connect Courtright to a powerhouse carved out of granite near Wishon. The powerhouse generators produce energy when electrical energy demand is high in the daytime and pumps take excess energy from nuclear power plants to pump water back up to Courtright when demand is low at night. The energy from nuclear power plants is therefore stored as gravitational potential energy of the weight of the water in Courtright reservoir.

Finally, what really is involved when I drop a pen in the classroom.

1. The big bang of the universe produced protons and electrons which become hydrogen gas.
2. Some of that hydrogen gas was collapsed by gravity to form our sun several billion years ago.
3. That hydrogen gas was heated up by gravitational collapse to a temperature so high that nuclear reactions could happen converting the hydrogen to helium and giving off nuclear fusion energy.
4. That nuclear fusion energy comes to the earth as sunlight.
5. Plants use that sunlight energy to make carbohydrates and other food.
6. Animals like use eat the plant food to keep us warmer than the outside temperature and to power our brain and muscles.
7. Our muscles use a bit of that energy to lift an object giving it some gravitational energy compared to what it had resting on the floor.
8. When released, that gravitational energy is converted to kinetic energy as it speeds up.
9. When it hits the floor, its kinetic energy is converted to heat and sound energy.
10. The sound energy also becomes heat energy after bouncing around the room.

In the end, the heat energy produced is dispersed energy and unable to be harnessed to undo the process. All energy in the universe will eventually become dispersed and useless.