1. *The metabolic rate* is defined as the rate at which the body uses chemical energy to sustain life functions. The average metabolic rate has been found to be proportional to the total skin surface area of the body. The surface area for a 5-ft, 10-in male weighing 175 lb is about 2.0 m\(^2\), and for a 5-ft, 4-in female weighing 110 lb it is approximately 1.5 m\(^2\). There is about a 1 percent change in surface area for every three pounds above or below the weights quoted here and a 1 percent change for every inch above or below the heights quoted.

(a) Estimate your average metabolic rate over the course of a day using the following guide for metabolic rates (per square meter of skin area) for various physical activities: sleeping, 40 W/m\(^2\); sitting, 60 W/m\(^2\); walking 160 W/m\(^2\); moderate physical activity, 175 W/m\(^2\); and moderate aerobic exercise, 300 W/m\(^2\). How do your results compare to the power of a 100 W light bulb?

(b) Express your average metabolic rate in terms of kcal/day (1 kcal = 4.19 kJ). (A kcal is the “food calorie” used by nutritionists.)

(c) An estimate used by nutritionists is that each day the “average person” must eat roughly 12-15 kcal of food for each pound of body weight to maintain his or her weight. From the calculations in Part (b), are these estimates plausible?
2. Assume that your maximum metabolic rate (the maximum rate at which your body uses its chemical energy) is 1500 W (about 2.7 hp). Assuming a 40 percent efficiency for the conversion of chemical energy into mechanical energy, estimate the following:

(a) The shortest time you could run up four flights of stairs if each flight is 3.5 m high,

(b) the shortest time you could climb the Empire State Building (102 stories high) using your Part (a) result. Comment on the feasibility of you actually achieving your Part (b) result.
3. A 3.0 kg block slides along a frictionless horizontal surface with a speed of 7.0 m/s. After sliding a distance of 2.0 m, the block makes a smooth transition to a frictionless ramp inclined at an angle of 40° to the horizontal. What distance along the ramp does the block slide before coming momentarily to rest?
4. A girl of mass $m$ is taking a picnic lunch to her grandmother. She ties a rope of length $R$ to a tree branch over a creek and starts to swing from rest at a point that is a distance $R/2$ lower than the branch. What is the maximum breaking tension for the rope if it is not to break and drop the girl into the creek?
5. The 2.0 kg block in the figure slides down a frictionless curved ramp, starting from rest at a height of 3.0 m. The block then slides 9.0 m on a rough horizontal surface before coming to rest.

(a) What is the speed of the block at the bottom of the ramp?

(b) What is the energy dissipated by the friction?

(c) What is the coefficient of kinetic friction between the block and the horizontal surface?
6. A small object of mass $m$ moves in a horizontal circle of radius $r$ on a rough table. It is attached to a horizontal spring fixed at the center of the circle. The speed of the object is initially $v_0$. After completing one full trip around the circle, the speed of the object is $0.5v_0$.

(a) Find the energy dissipated by friction during that one revolution in terms of $m$, $v_0$, and $r$.

(b) What is the coefficient of kinetic friction?

(c) How many more revolutions will the object make before coming to rest?
7. If a black hole and a “normal” star orbit each other, gases from the normal star falling into the black hole can have their temperatures increased by millions of degrees due to frictional heating. When the gases are heated that much, they begin to radiate light in the X-ray region of the electromagnetic spectrum (high-energy light photons). Cygnus X-1, the second strongest known X-ray source in the sky, is thought to be one such binary system; it radiates at an estimated power of $4 \times 10^{31}$ W. If we assume that 1.0 percent of the in-falling mass escapes as X-ray energy, at what rate is the black hole gaining mass?
8. A large nuclear power plant produces 1000 MW of electrical power by nuclear fission.

(a) By how many kilograms does the mass of the nuclear fuel decrease in one year? (Assume an efficiency of 33 percent for a nuclear power plant.)

(b) In a coal-burning power plant, each kilogram of coal releases 31 MJ of thermal energy when burned. How many kilograms of coal are needed each year for a 1000 MW coal-burning power plant? (Assume an efficiency of 38 percent for a coal-burning power plant.)
9. In particle physics, the potential energy associated with a pair of quarks bound together by the strong nuclear force is in one particular theoretical model written as the following function: \( U(r) = -\left(\frac{\alpha}{r}\right) + kr \), where \( k \) and \( \alpha \) are positive constants, and \( r \) is the distance of separation between the two quarks.

(a) Sketch the general shape of the potential-energy function.

(b) What is a general form for the force each quark exerts on the other?

(c) At the two extremes of very small and very large values of \( r \), what does the force simplify to?
10. In one model of a person jogging, the energy expended is assumed to go into accelerating and decelerating the feet and the lower portions of the legs. If the jogging speed is \( v \), then the maximum speed of the foot and lower leg is about \( 2v \). (From the moment a foot leaves the ground, to the moment it next contacts the ground, the foot travels nearly twice as far as the torso, so it must be going, on average, nearly twice as fast as the torso.) If the mass of the foot and lower portion of a leg is \( m \), the energy needed to accelerate the foot and lower portion of a leg from rest to speed \( 2v \) is \( \frac{1}{2}m(2v)^2 = 2mv^2 \), and the same energy is needed to decelerate this mass back to rest for the next stride. Assume that the mass of the foot and lower portion of a man’s leg is 5.0 kg and that he jogs at a speed of 3.0 m/s with 1.0 m between one footfall and the next. The energy he must provide to each leg in each 2.0 m of travel is \( 2mv^2 \), so the energy he must provide to both legs during each second of jogging is \( 6mv^2 \). Calculate the rate of the man’s energy expenditure using this model, assuming that his muscles have an efficiency of 20 percent.