PHYSICS 1020

Homework set 7

5 February 1997

[7.6] When we say that the motion of a rock swinging on a string is irreversible, do we really mean that it is impossible to get the rock back to its starting condition? Explain.
Answer:
The statement that the motion of a rock swinging on a string is irreversible means that some of the gravitational potential energy that the rock had at the beginning of its motion has been converted into thermal energy (by friction and air resistance), thus causing a slight increase of the temperature of its environment. This energy will not spontaneously convert itself back into gravitational energy. A heat engine could use this thermal energy as input to generate work to lift the rock back up, but the 2nd law tells us that only a fraction of the thermal energy could be converted into work, the rest being exhausted to a lower temperature reservoir. Thus we would need an additional source of mechanical energy (work) to lift the rock back up.

[7.7] Can you think of any way to drive a ship across the ocean by using the ocean's thermal energy, without violating the second law?
Answer:
This would only be possible if we had access to a heat reservoir at lower temperature than that of the ocean; the exhaust heat of the heat engine would be ejected into this reservoir (i.e. this colder reservoir would be used for cooling the exhaust end of the heat engine). One possibility would be to use the ocean water deeper down which is cooler than the water at the surface.

[7.10] In one cycle of its operation, a heat engine consumes 1500 J of thermal energy while performing 300 J of work. What is its efficiency? How much energy is exhausted in each cycle?
Answer:
Efficiency = (work out)/(heat in) = 300 J/1500 J = 0.2 = 20%. The energy exhausted each cycle = (heat in) - (work out) = 1500 J - 300 J = 1200 J.

[7.19] Which method of fueling your car is likely to be more energy efficient, and why: gasoline used in a standard gas engine or electricity taken from a coal-fueled generating plant and stored in lightweight car batteries? Assume that the batteries convert electricity to work at 100 % efficiency.
Answer:
Since generating plants are appreciably more efficient (typically 40%) than car engines (typically 10 to 15%), it is more efficient to use batteries charged using electrical power from a generating plant. (see table 7.1).

[7.21] For every 100 kg of coal entering a generating plant (recall that this enters every second), about 15 kilograms of sulfur oxides and ash are removed, producing a significant solid-waste disposal problem. For a typical 1000 MW plant, how much if this solid waste is produced every day? Express your answer in tonnes (1 tonne = 1000 kg).
Answer:
One day = $24 \times 3600 = 8.64 \times 10^4$ seconds; so the total amount of solid waste per day = $15 \times 8.64 \times 10^4$ kg/day $= 1.3 \times 10^6$ kg/day = 1300 tonnes per day.

[**7.23**] Making estimates: In the United States, solar energy strikes a single square meter of ground at an average rate (averaged over day and night and over the different seasons) of 200 watts. At what average rate does solar energy strike a football field (about 100 m by 30 m)? A typical home in the United States consumes electricity at an average rate of 1 kW. How much surface area would be needed to provide this electric power, assuming a 10 % conversion efficiency? What dimensions would a square-shaped photovoltaic collector need to cover this area?
Answer:
The area of a football field $= 100\ \mathrm{m} \times 30\ \mathrm{m} = 3000\ \mathrm{m}^2$;
it receives on the average $3000\ \mathrm{m}^2 \times 200\ \mathrm{W/m}^2 = 6 \times 10^5\mathrm{W}$.
To supply a home we need 10 kW (allowing for the 10% conversion efficiency); this power is received from the Sun by an area of 50 m^2, i.e. a square whose side is about 7.1 m long. A football field covered with photovoltaic cells could provide the energy supply for 12000 homes.

[**7.24**] A lily pond doubles the number of lilies every month. One day, you notice that 2% of the pond is covered. About how long will it be before the pond is entirely covered?
Answer:
The doubling time is 1 month, so in two months the pond will be covered to 8%, in four months to 32%, in five months to 64%. In six months this would be 128%, i.e. more than is available. So it will take somewhere between five and six months. To get the precise number, you must figure out how many doubling times it takes to go from 2% to 100% coverage, i.e. you have to solve the following equation for the doubling time x:

$$\frac{100\%}{2\%} = 2^x \quad \Rightarrow \quad x = \frac{\log 50}{\log 2}$$

So, the pond will be fully covered in 5.64 doubling times, i.e. 5.64 months from now.