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Problems set # 4 **Physics 131** October 9, 2018

1. The escape velocity is the minimum speed needed for an object to "break free" from the gravitational attraction of a massive body. More particularly, the escape velocity is the speed at which the sum of an object's kinetic energy and its gravitational potential energy is equal to zero. Show that the escape velocity from Earth is about 25,020 miles per hour.

2. The energy gained by a person climbing to the top of Mt. Washington is about 300 calories (0.35 kWh). This also happens to be the amount of energy released by burning about 1 ounce of oil. *(i)* If for every calorie of useful work done the body expends 5 calories in heat, what is the weight loss resulting from the climb? *(ii)* If you were to perform this climb, would you expect to regain weight during the trip down? Why not?

3. A car engine derives its thermal energy from a "reservoir" of burning fuel whose average temperature is about $4,000°$F. The release of the exhaust takes place at a "cold" temperature of about 180°F. What is the theoretical efficiency of the car engine? Note that in the absolute scale for Farenheit degrees, we use Rankine (°R) temperatures. Zero on both the Kelvin and Rankine scales is absolute zero, but the Rankine degree is defined as equal to one Fahrenheit degree, rather than the Celsius degree used on the Kelvin scale. A temperature of $-459.67°$F is exactly equal to 0°R.

4. Biological energy. *(i)* Suppose a person were entirely made of water (not a bad approximation). If all the heat generated by the body during the day ($3,000$ Cal $=$ $12,000$ Btu) were used to warm up the body, what would be the body temperature at the end of the day for a person weighing 120 lb? Assume an initial temperature of 98.6°F. *(ii)* If $1,600$ Cal were used to work at 25% efficiency, how high could a 120 lb person climb in the day? (1 Btu = 800 ft lb.)

5. It is well known that a heavy rhinoceros is harder to stop than a small dog at the same speed. We state this fact by saying that the rhino has more *momentum* than the dog. And if two dogs have the same mass, the faster one is harder to stop than the slower one. So we also say that the faster moving dog has more momentum than the slower one. By *momentum* we mean the product of the mass of an object and its velocity

$$\text{momentum} = \text{mass} \times \text{velocity}\,. \tag{1}$$

When the direction is not an important factor , we can say

$$\text{momentum} = \text{mass} \times \text{speed}\,. \tag{2}$$

Conservation of momentum is a fundamental law of physics, which states that the momentum of a system is constant if there are no external forces acting on the system. Momentum conservation is especially useful for collisions. The forces involved may be so complicated that you cannot practically use *Newton's second law of motion* to figure out what happens. And, since some energy may go into heat, sound, or deformation in a collision, energy conservation may also not be useful. But as long as there are no *outside* forces involved (only internal ones, no matter how big!) then mometum conservation often lets you figure out the outcomes! For example, a crater in Arizona is thought to have been formed by the impact of a meteorite with the Earth over 20,000 years ago. The mass of the meteorite is estimated at 5×10^{10} kg and its speed $7,200$ m/s. *(i)* Judging from a frame of reference in which the Earth is initially at rest, what speed would such a meteor impart to the Earth in a head-on collision? Assume the pieces of the shattered meteor stayed with the earth as it moved. *(ii)* What fraction of meteor's kinetic energy was transformed to kinetic energy of Earth? *(iii)* By how much did Earth kinetic energy change as a result of this collision? The mass of the Earth is $M_\oplus = 6 \times 10^{24}$ kg.