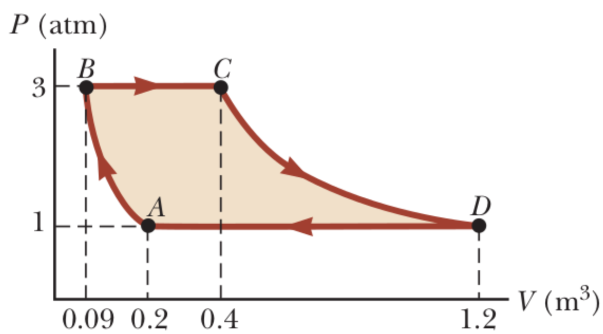
PHY121 Summer 2018
Problem Set #10/11
Due Tuesday 6/26

1. An ideal gas is taken through a quasi-static process described by $P = \alpha V^2$, with $\alpha = 5.00\ \text{atm/m}^6$. The gas is expanded to twice its original volume of 1 m^3. How much work is done on the expanding gas in this process?

2. A sample of an ideal gas goes through the process shown. From A to B, the process is adiabatic; from B to C, it is isobaric with 100 kJ of energy entering the system by heat; from C to D, the process is isothermal; and from D to A, it is isobaric with 150 kJ of energy leaving the system by heat. Determine the difference in internal energy $U_B - U_A$.



3. One mole of an ideal gas is contained in a cylinder with a movable piston. The initial pressure, volume, and temperature are P_i, V_i, and T_i, respectively. Find the work done on the gas in the following processes. In operational terms, describe how to carry out each process (i.e. what do you have to do with the piston or to the system) and show each process on a PV diagram.

   (a) An isobaric compression in which the final volume is one-half the initial volume.

   (b) An isothermal compression in which the final pressure is four times the initial pressure.

   (c) An isovolumetric process in which the final pressure is three times the initial pressure.

4. Draw a spacetime diagram that shows the following worldlines:

   (a) A particle traveling at a constant speed of $\frac{3}{5}$ in the $-x$ direction that passes $x = 0$ at time $t = -2$ s.

   (b) A particle that at time $t = 0$ is at rest at position $x = 0$ but accelerates in the $+x$ direction, asymptotically approaching the speed of light as time passes.

   (c) A light flash that passes the position $x = 0$ at time $t = +3$ s as it travels in the $-x$ direction.

5. Two radar pulses sent from the Earth at 0600 and 0800 (on the same day) bounce off an alien spaceship and are detected on Earth at 1500 and 1600 (but you aren't sure which reflected pulse corresponds to which emitted pulse). Is the spaceship moving toward Earth or away from it? If its speed is constant, when will it (or did it) pass the Earth? (Hint: Draw a spacetime diagram.)

6. Alice is sitting at one end of a train speeding around a circular track at 0.9c. Bob is standing on a platform next to the track. Charlie is flying overhead in an aircraft at a constant velocity of 0.7c. As Alice passes Bob, he shoots off a flare. The next time Alice comes around, Bob shoots off another flare. List the types of time measured by each person between the flares. Who observes the shortest time? Why?

7. At $t = 0$, an alien spaceship passes by the Earth. Let this be event A. At $t = 13$ min (according to synchronized clocks on Earth and Mars) the spaceship passes by Mars, which is 5 light-minutes from Earth at the time. Let this be event B. Radar tracking indicates that the spaceship moves at a constant velocity between Earth and Mars. Just after the ship passes Earth, NASA launches a probe whose purpose is to catch up with and investigate the spaceship. This probe accelerates away from Earth, moving slowly at first but moving more quickly until it eventually catches up with and passes the alien ship, just as they both pass Mars. (Ignore gravity and the relative motion of Earth and Mars; assume both spacecraft carry clocks.)

   (a) Draw a quantitatively accurate spacetime diagram of the situation, including labeled worldlines for Earth, Mars, the alien spacecraft, and the probe. Also label events A and B.

   (b) Whose clocks measure coordinate times between events A and B? Explain carefully.

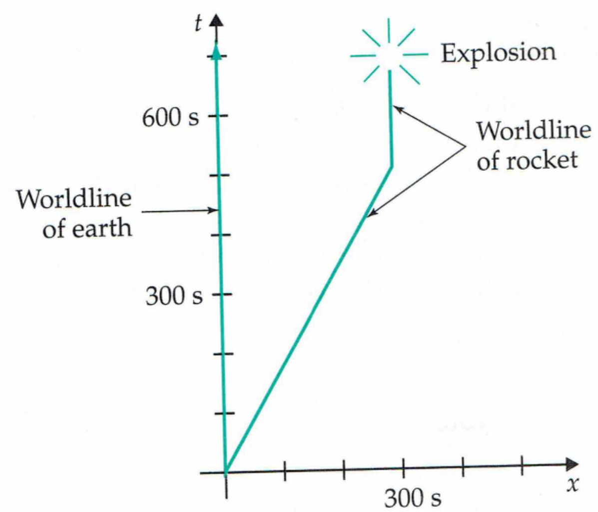
   (c) Whose clocks measure proper times between these events? Explain.

   (d) Does any clock in this problem measure the spacetime interval between the events? If so, which one and why? If not, why not?

8. The spacetime diagram below shows the worldline of a rocket as it leaves the Earth, travels for a certain time, comes to a stop, then explodes.

   (a) What is the elapsed time between the rocket's departure and explosion, as measured by a clock on the rocket?

   (b) What is the spacetime interval between these two events?



9. In 2095 a message arrives from the growing colony of Tau Ceti, 11.3 y from Earth. The message contains the entire genome for a virus that is making people seriously ill and asks for help. Using advanced technology available on Earth, scientists are able to construct a drug that prevents the virus from reproducing. The probes available on short notice are able to boost 200 g to a speed of 0.95, 1 kg to a speed of 0.9, 5 kg to a speed of 0.8, or 20 kg to a speed of 0.6 (relative to the Earth). There's a problem, however: a sample of the drug in the laboratory is observed to degrade due to chemical processes at a rate that will make it useless after 5 y. Is it possible to send the drug to Tau Ceti? If so, what is the maximum amount you can send?

10. On a particular mission, the astronauts aboard the Space Shuttle go into Low Earth Orbit (LEO) for 14 days 3.45 hours, as measured by a clock at Cape Canaveral (where shuttles are launched from and land). About how much less time passed between departure and arrival according to the astronauts' clocks compared to the ground-based clocks? (Assume for the sake of this question that the surface of the Earth defines an inertial reference frame; for this particular mission, LEO is at 300 km).