PHYS 182 Fall 2019 Prof. R. Brandenberger

Readings and Homework for Week of Oct. 14 2019

Readings

Textbook, Chapters S4, 14.

Problems (due Oct. 23 in class)

1. Assume you are at a point on the equator and your friend travel with $0.9c$ ten times around the earth (along the equator). How much time elapses according to your watch? How much time elapses according to your friend's watch? Take the value of the speed of light and of the radius of the earth from the textbook.

2. A spacecraft emits laser light at the frequency ν_b of blue light in direction of its motion. How do you perceive the laser signal if the spacecraft is heading straight towards you with a velocity of $\sqrt{5}/3$ times the speed of light (the strange value of the speed is chosen to make the algebra easy)? What is the frequency at which you observe the signal, and what kind of radiation does this correspond to (the second question asks for a qualitative answer)?

3/4. Garage paradox: a care is moving towards a garage with the same speed as in the previous problem. The garage is $8m$ long and the car is $9m$ long. The person sitting at rest beside the garage sees the car shorter and thinks that the car will fit into the garage. On the other hand, the driver of the car sees the garage approaching the car and for him/her the garage appears shorter, and the driver concludes that the car will not fit. Explain why the two observers reach their respective conclusions. Why do they reach different conclusions?

5. The universe is expanding. Consider a measuring stick made out of wood. Is this stick also expanding? Why or why not?

6/7. (*) In class I discussed the expansion of the universe and gave the formula

$$H^2 = \frac{8\pi G}{3}\rho$$

where H is the expansion rate, G is Newton's gravitational constant, and ρ is the density of energy. Based on this equation, argue that that there was a point in the past when the density was infinite (this is the Big Bang). I am looking for a qualitative argument. To give such an argument, think about what *expansion rate* means, what *energy density* means and what happens to the energy density when you go back in time when the universe was smaller.

E For those of you who have taken calculus, for extra credit you can solve the problem using calculus. You will need to use

$$H(t) = \dot{a}/a$$

where $a(t)$ is proportional to the size of the universe (it is the scale factor), and you will need to use the scaling $\rho(t) = \rho_0 a(t)^{-3}$ where ρ_0 is a constant.

8. What is the uncertainty in an electron's speed if you can measure its location to within 10^{-10}m?

9. In class I discussed that the classical vacuum is teaming with virtual particle/antiparticle pairs. Consider a box of radius 10^{-1-}m which is empty of classical particles, i.e. which is in a vacuum state. How long can a virtual electron in this box exist for. What about a virtual quark (consider the quark mass to be the same as the proton mass)?

10. Explain in your own words why hydrogen atoms are stable if you take quantum effects into account (less than half a page).

NB: The problem marked (*) is challenging.