UNIVERSITY OF SURREY

Department of Physics

Space, Time and Relativity

Tutorial Sheet 2

Questions:

(a) Two overlapping inertial frames are in relative motion. According to the first principle of relativity, which of the quantities on the following list must *necessarily* be the same as measured in the two frames and Which quantities are *not* necessarily the same?

- numerical value of the speed of light in a vacuum
- speed of an electron
- value of the charge on an electron
- kinetic energy of a proton
- value of the electric field at a given point
- time between two events
- order of elements in the periodic table
- Newton's first law of motion

(b) When Einstein was 16 he thought about the following problem: A runner looks at himself in a mirror that he holds at arms length in front of him. If he runs with nearly the speed of light, will he be able to see himself in the mirror? Analyse this question using the second principle of relativity.

(c) In certain high energy nuclear reactions, a beam of oxygen nuclei collide head-on with a beam of lead nuclei (both of which can be considered to be spherical at rest). At high enough energy, the region where two colliding nuclei overlap has a density, and hence a temperature, high enough to create what is called a quark-gluon plasma. Explain how length-contraction can help to achieve this.

Problems:

(1) Suppose that an event occurs in inertial frame S at $x = 100$ km, $y = 10$ km, $z = 1$ km at $t = 2.0 \times 10^{-4}$ seconds. Let frame S' move relative to S at $v = 0.95c$ along the common

$x - x'$ axis, the origins coinciding at $t' = t = 0$. What are the coordinates x', y', z', and t' of this event in S'? Check the answer by using the inverse transformation to obtain the original data.

(2) At what speed v will the Galilean and Lorentz expressions for x' differ by 1 percent and 10 percent?

(3) The length of a spaceship is measured to be exactly half its proper length. (a) what is the speed of the spaceship relative to the observer's frame? (b) What is the dilation of the spaceship's unit time?

(4) The radius of our galaxy is 3×10^{20} m, or about 3×10^4 light-years. (a) Can a person, in principle, travel from the centre to the edge of our galaxy in a normal lifetime? Explain using either time-dilation or length-contraction arguments. (b) What constant velocity would she need to make the trip in 30 years as measured in the rocket?

(5) Consider a universe in which the speed of light is 100 km/h. A bus travelling at a speed v relative to a fixed radar speed trap overtakes a car travelling at the speed limit of 50 km/h $= c/2$. The speed of the bus is such that its length is measured by the fixed observer to be the same as that of the car. By how much is the bus exceeding the speed limit? The proper length of the bus is twice that of car.

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