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Relativistic Kinematics

Question 1. While investigating whether the so-called "Pioneer Anomaly"[1] could affect the Voyager 1 space probe, NASA engineers determined a need to calculate the momentum of Voyager 1 to within 1 ppb (part per billion). Voyager 1 has escaped our solar system and is now traveling at about 17 km/s. The mass of Voyager 1 is 722 kg. Is the classical formula for the momentum adequate for the demands of the NASA engineers?

For the rest of the worksheet, we will look at some of the practical considerations involved with objects traveling near the speed of light.

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[1] See http://en.wikipedia.org/wiki/Pioneer_anomaly for example. The anomaly was a long-unexplained discrepancy in the deep space acceleration of the Pioneer craft.

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You're a venture capitalist that is asked to invest in a startup company that claims it will be able to launch tiny "micro space probes" into space at close to the speed of light using a massive electromagnetic rail gun system[2]. You're cynical about their cost estimates and decide to analyze the problem in more detail before you invest in their company. Neglect air resistance for this worksheet.

Question 2. A typical payload they claim to launch will weigh 1 kilogram and be accelerated to 90% the speed of light. How much electrical energy will the rail gun require to launch the probe, assuming it is 20% efficient at converting electrical energy to projectile kinetic energy?

Question 3. Assuming that typical electrical costs are about 15 cents per kW-h, how much would this launch cost? Would you invest in this company?

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[2] http://en.wikipedia.org/wiki/Railgun

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Question 4. You're also concerned about safety. What happens if this projectile were to hit an airplane that is flying overhead and dissipate all of its kinetic energy in the collision? To give you a sense of scale, a large nuclear explosion generates about 10^{15} J of energy.

Question 5. The system must be able to launch probes in any direction and must be transportable on a ship. Assume that the rail gun is mounted on a frigate-class navy ship (weight = 4,000 metric tons).

a. Will the recoil momentum of the ship be relativistic? Justify your argument mathematically.

b. At what speed will the ship recoil after it launches a probe? What would be the consequence of this event?

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Question 6. Assuming Voyager 1 could have been launched to its final speed of 17 km/s by the same rail gun as in Question 2, how much would the launch cost?