Modern Physics (PHY 3305) Lecture Notes

HomeworkAssignment002

SteveSekula, 28 January 2010 (created 26 January 2010)

no tags

Expectations for the quality of your handed-in homework are available at http://www.physics.smu.edu/sekula/phy3305/homework.pdf. Failure to meet these guidelines will result in loss of points as detailed in that document. This assignment covers material from Harris Ch. 2.4-2.7 and is worth 100 points.

- HARRIS, *CH2-14* (20 Points)
- *SS-4* (see below)
- HARRIS, *CH2-65* (20 Points)
- HARRIS, *CH2-81* (20 Points)
- *SS-5* (see below)

PROBLEM *SS-4* (20 Points)

In 1997, the United States and European space agencies (NASA and ESA, respectively) launched a joint mission to the planet Saturn. The goal was to study the rings and moons of Saturn to better understand the evolution of the solar system. The satellite, named Cassini, contained on board a probe, named Huygens, designed to reach the surface of Titan, Saturn's largest moon. Titan was of particular interest because it contained the chemical building blocks of life - organic compounds - yet no one had ever seen beneath its thick methane clouds.

Huygens was launched from Cassini in December 2004 and 22 days later entered the atmosphere of Titan. Huygens was designed to send back video and audio of its journey. Data from Huygens was transmitted back to Cassini and relayed to Earth. The data was sent from Huygens using S-band radio waves, with a frequency range of 2.0-4.0 *GHz*, using a technique called "phase-shift keying" whereby information is sent from Huygens in packets at a rate of 8192 bits/second. The receiver on Cassini was tuned to receive S-band and the firmware on the satellite was written

to expect information in packets that contained precisely 8192 bits/second; a large mis-match in frequency between the two, or the loss of bits from the packets, means catastrophic loss of data.

1. While Huygens itself is descending to Titan at a speed of about 200 km/h (relative to the surface of Titan), the original Cassini flight plan was designed so that it and the Huygens probe were moving away from one another at a MUCH larger speed - more like 10.0×10^3 km/h. What is the Doppler Shift on transmissions from Huygens back to Cassini at this relative speed? Which Doppler Shift is bigger: that due solely to relative motion, or the time dilation effect? *(HINT: Remember your Binomial Expansion.)*
2. Is the frequency Doppler Shift enough to prevent the receiver from seeing the data? How does the Doppler Shift affect the number of bits/second that are received by the Cassini satellite (rounding to the nearest bit)?
3. The design of the transmitter/receiver system actually failed to take into account the Doppler Shift. This oversight was discovered when Cassini passed by Earth on its way to Saturn. Would this mistake have the potential to doom the Huygens mission? Please briefly explain why based on your answers to the previous part of this question.
4. The firmware could not be altered after launch. Pretend that you are an engineer working at NASA or ESA on the project, and you are under tremendous pressure to minimize the impact of the Doppler Shift *after* the satellite has already headed out to Saturn (after all, the project cost $3.26 billion and you can't let its success be threatened). Given that you cannot alter the receiver/transmitter design, hardware, or firmware (or any other programming on that equipment) to address this issue, how would you adjust the *flight plan* of the satellite to minimize the impact of the Doppler Shift?

PROBLEM *SS-5* (20 Points)

Einstein's recognition that mass and energy are two aspects of the same thing helped to lead to the prediction of a new form of matter called "anti-matter." As its name implies, when anti-matter and matter meet they completely annihilate each other. All of their mass is converted into pure radiation (e.g. light).

1. Imagine that there is exactly one gram of anti-matter, and it contacts

and completely annihilates with exactly one gram of matter. Assume that each gram is brought into contact very, very slowly, so that you can ignore momentum. How much energy is released? Compare that to the energy released by a hydrogen bomb, the most powerful weapon ever devised, whose explosion is equivalent to 50 million tons of TNT (1 ton of TNT is equivalent to 4.184×10^9 Joules of energy).

2. In the movie and the book "Angels and Demons," a tiny amount of anti-matter is stolen from CERN, a global center for subatomic particle physics research. While CERN is real, and anti-matter is real, the technology featured in the movie which stores and isolates anti-matter is not real. However, accepting the premise, imagine that, as in the movie, a quarter of a gram of anti-matter is suddenly brought into contact above Vatican City and Rome. Should we have expected the story to continue - that is, would anybody have survived the event and gone on to find the killer?
3. Given your answers to the first two questions, is anti-matter abundant on Earth? Please explain your answer.