AAPT UNITED STATES PHYSICS TEAM
AIP 2009

Quarterfinal Exam

DO NOT DISTRIBUTE THIS PAGE

Important Instructions for the Exam Supervisor

- This examination consists of one part.
- The first page that follows is a cover sheet. Examinees may keep the cover sheet during the exam.
- Allow 60 minutes to complete the exam. Examinees may read the cover sheet before beginning the exam, but may not look at the examination questions until the 60 minute time period begins.
- The supervisor *must* collect all examination questions, including the cover sheet, at the end of the exam, as well as any scratch paper used by the examinees. Examinees may *not* take the exam questions. The examination questions may be returned to the students after March 8, 2009.
- Examinees are allowed calculators, but they may not use symbolic math, programming, or graphic features of these calculators. Calculators may not be shared and their memory must be cleared of data and programs. Cell phones, PDA's or cameras may not be used during the exam or while the exam papers are present. Examinees may not use any tables, books, or collections of formulas.
- **The examinees will need to use a ruler for one of the questions on this exam.** They may *not* share rulers with other examinees.
- AAPT *must* receive the students answer papers no later than Thursday, March 5, 2009. Marking of papers will occur that weekend, and the semifinalists will be selected by March 8, 2009. It will not be possible to mark late papers.

AAPT UNITED STATES PHYSICS TEAM
AIP 2009

2009 Quarter-Final Exam

4 QUESTIONS - 60 MINUTES

INSTRUCTIONS

DO NOT OPEN THIS TEST UNTIL YOU ARE TOLD TO BEGIN

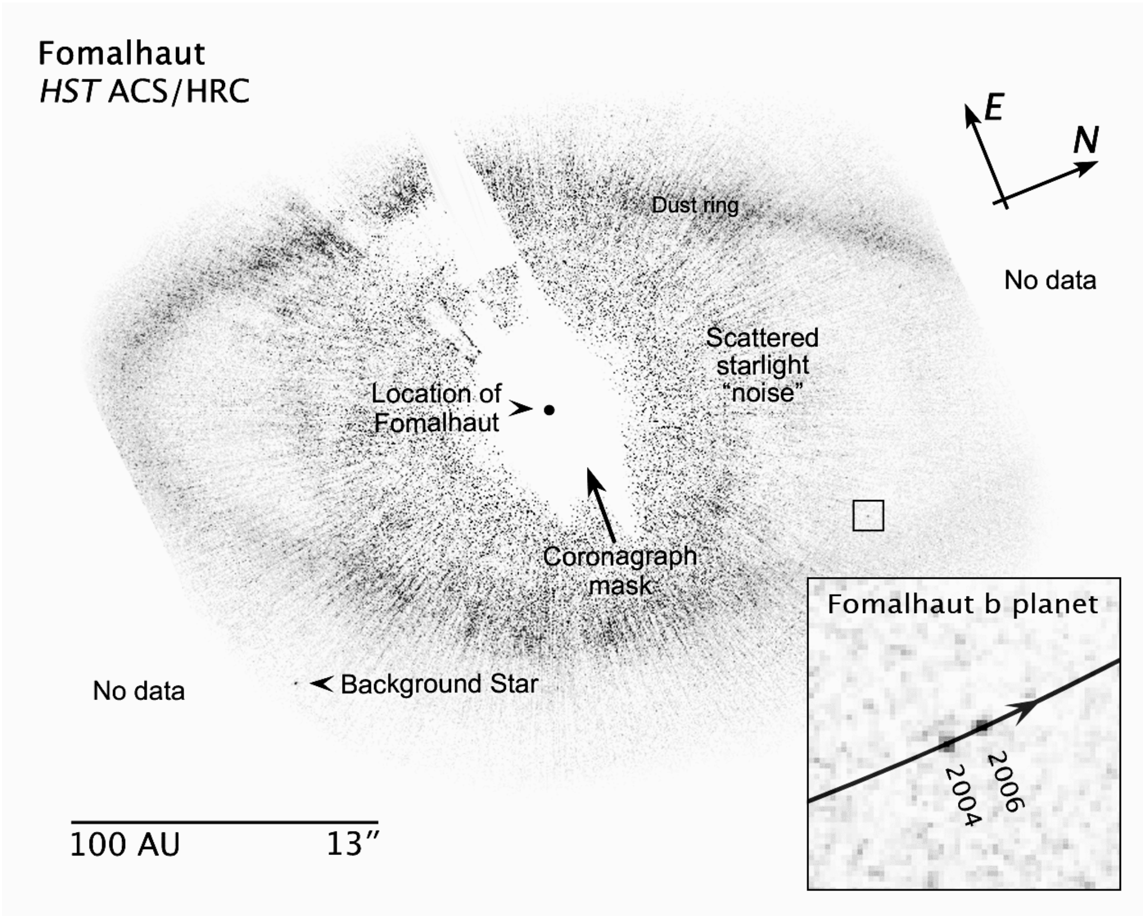
- Show all your work. Partial credit will be given.
- Start each question on a new sheet of paper. Put your name in the upper right-hand corner of each page, along with the question number and the page number/total pages for this problem. For example,

  Doe, Jamie

  Prob. 1 - P. 1/3

- A ruler will be required on this exam.
- A hand-held calculator may be used. Its memory must be cleared of data and programs. You may use only the basic functions found on a simple scientific calculator. Calculators may not be shared.
- Cell phones may not be used during the exam or while the exam papers are present. You may not use any tables, books, or collections of formulas.
- Each of the four questions is worth 25 points. The questions are not necessarily of the same difficulty. Good luck!
- **In order to maintain exam security, do not communicate any information about the questions (or their answers or solutions) on this contest until after March 10, 2009.**

1. Below is an image of Fomalhaut b, the first extrasolar planet to be observed directly by visible light, obtained by the Hubble Space Telescope.



Astronomy Picture of the Day 2008 November 14 http://antwrp.gsfc.nasa.gov/apod/ap081114.html
Image Credit: NASA, ESA, P. Kalas, J. Graham, E. Chiang, E. Kite (Univ. California, Berkeley), M. Clampin (NASA/Goddard), M. Fitzgerald (Lawrence Livermore NL), K. Stapelfeldt, J. Krist (NASA/JPL)

The scale of the larger diagram is shown on the lower left; the 13" refers to the angle, in arc-second, subtended by 100 AU at the distance of Fomalhaut. The scale of the inset can be determined by size of the small box.

(a) A planet is in a circular orbit of radius R and period T. Derive an expression for the mass of a star in terms of R, T, and the gravitational constant G. You may assume that the mass of the planet is much, much less than the mass of the star.

(b) From the image, estimate the mass of the star Fomalhaut in solar masses. You may assume that the orbit of Fomalhaut b is circular and ignore any errors associated with the fact that the plane of the image is not coincident with the plane of the orbit. Recall that the radius of the Earth's orbit around the Sun is 1 AU. You do not need to do an error analysis, but the number of significant digits in your answer ought reflect the accuracy of your answer.

2. A ball of mass m is thrown vertically upward with a speed of v_0. The ball is subject to an air resistance force that is proportional to the velocity, $F = -kv$. The ball rises up to height of h and then returns to the starting point after some total time t_f. The acceleration of free fall is g.

   Determine the following:

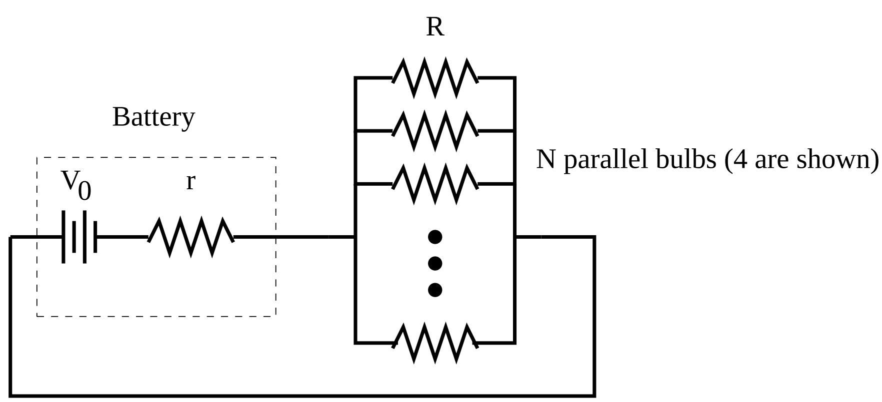
   (a) An expression for the velocity as a function of time in terms of any or all of the constants.

   (b) Sketch the graph of velocity vs time. On the sketch indicate the time to rise to the highest point, t_r, and the total time of flight, t_f. You do not need to find either t_r or t_f at this point, but your graph should reflect relative positions of both.

   (c) Find the time to rise, t_r, to the highest point, h, in terms of any or all of the constants.

3. A parallel plate capacitor is made of two square parallel plates of area A, and separated by a distance $d \ll \sqrt{A}$. The capacitor is connected to a battery with potential V and allowed to fully charge. The battery is then disconnected. A square metal conducting slab also with area A but thickness $d/2$ is then fully inserted between the plates, so that it is always parallel to the plates. How much work has been done on the metal slab while it is being inserted?

4. A certain electric battery is not quite ideal. It can be thought of as a perfect cell with constant output voltage V_0 connected in series to a resistance r, but there is no way to remove this internal resistance from the battery.



   The battery is connected to N identical lightbulbs in parallel. The bulbs each have a fixed resistance R, independent of the current through them.

   (a) Derive an expression for the total power dissipated by the N bulbs in terms of r, R, and V_0.

   (b) It is observed that the configuration dissipates more total power through the bulbs when $N = 5$ than it does for any other value of N. In terms of R, what *range* of values is possible for r?