University of Louisville
College of Arts and Sciences

Department of Physics and Astronomy PhD Qualifying Examination (Part I)

Spring 2016

Paper E – Contemporary Physics

Time allowed – 45 minutes each section

Instructions and Information:

- ***Attempt any 2 of the 6 questions***
- This is a closed book examination
- Start each question on a new sheet of paper – use only one side of each sheet
- Write your identification number on the upper right hand corner of each answer sheet
- You may use a non programmable calculator
- Partial credit will be awarded.
- Correct answers without adequate explanations will not receive full credit.
- Make sure your work is legible and clear
- The points assigned to each part of each question is clearly indicated

Nuclear & Particle Physics

Consider the decay of the Λ^0,

$$\Lambda^0 \rightarrow p + \pi^-$$

in the Λ^0 rest frame.
[Mass of Λ = 1115 MeV/c^2 , Mass of π = 140 MeV/c^2 , Mass of proton = 938 MeV/c^2 , c = 3 x 10^8 m/s]

(a) Determine the velocity of the π^- in this reference frame. (18)

(b) Determine the velocity of the proton in the same reference frame. (18)

(c) Calculate the velocity of the π^- in the rest frame of the proton. (18)

If the LHC collides two 7 TeV proton beams in their center of mass frame (CM) - the reference frame in which the momentum of the center of mass is zero.

(d) What proton beam energy would be necessary to produce the same CM frame energy when directed onto a stationary proton target ? (36)

(e) The CM energy available in either case is 14 TeV. However, experiments can expect less than 2.5 TeV of this energy to be available to create new particles. Explain why this is the case. (10)

Atmospheric Physics

Basic questions about the Earth's atmosphere

(a) Assuming an exponential pressure and density dependence with scale height H = 7.5 km, estimate the heights in the atmosphere at which the pressure is equal to 1 hPa. Use p_0 = 1000 hPa. (20)

(b) Under the same assumption as above, calculate the fraction of the total mass of the atmosphere that resides between 0 and 1 scale height, 1 and 2 scale height, and 2 and 3 scale heights, and so on above the surface. (20)

(c) A small blackbody satellite is orbiting the Earth at a distance far enough away so that the flux density of Earth radiation is negligible, compared to that of solar radiation. Suppose that the satellite suddenly passes into the Earth's shadow. At what rate will it initially cool? Assume that the satellite has a mass m = 10^3 kg, specific heat c = 10^3 J/kg/K and that it is spherical with a radius of 1 m and uniform surface temperature. (30)

(d) Calculate the equivalent blackbody temperature T_E of the solar photosphere (i.e., the outermost visible layer of the sun) based on the following information. The flux density of solar radiation reaching the Earth, F_s, is 1368 W m^{-2}. The Earth-sun distance d is 1.50 x 10^{11} m and the radius of the solar photosphere R_s is 7.00 x 10^8 m. (30)

Optics

A glass surface is to be coated with a thin film with an index of refraction of 1.2 in order to reduce the reflection from its surface at the wavelength of 500 nm. The glass has an index of refraction of 1.4.

(a) What is the minimum thickness of the coating that will minimize the intensity of the reflected light impinging from air at normal incidence ? (30)

(b) In the above case the intensity of the reflected light is small but not zero. Explain. What needs to be changed, and by how much, to make the intensity of the reflected light zero ? (70)

Atomic & Molecular Physics

Carbon dioxide and water molecules absorb infrared radiation but are largely transparent to ultraviolet and visible light.

(a) Why is it typical of molecules to have absorption spectra in the infrared, whereas atoms typically have strong absorption spectra in the ultraviolet or visible? (20)

(b) A blackbody with a temperature of 10,000 K emits a spectrum that peaks at about 300 nm in the ultraviolet. The Sun emits light almost as if it were a perfect blackbody with a temperature of around 6000 K. At what wavelength would this emission spectrum be maximum in flux of energy? (10)

(c) The Earth's average temperature is close to 275 K. Draw a sketch of the spectral energy distribution of the Earth's blackbody radiation. (10)

(d) What factors affect Earth's average surface temperature? Explain why the presence of water and carbon dioxide in its atmosphere result in a higher surface temperature than it would have with a clear atmosphere. (20)

(e) If Earth were 2x closer to the Sun than it is now, how would that affect its surface temperature and its atmosphere? (20)

(f) If you were asked to measure the concentration of carbon dioxide in Earth's atmosphere, how would you do it? Describe an instrument that could determine the concentration of CO_2 in a sample of gas. (20)

Astrophysics

Consider two galaxies, one a gas rich star-forming spiral galaxy and the other a passively evolving elliptical galaxy.

(a) At what wavelengths (far-UV, near-UV, optical, near-IR, mid-IR, far-IR) would you expect emission from the spiral galaxy and why would you expect flux at these wavelengths (ie. what sources contribute)? (30)

(b) Similarly at what wavelengths would you expect to see prominent emission from the elliptical galaxy and why? (30)

(c) Sketch the spectral energy distributions of these two galaxies. (10)

(d) Is there a lower wavelength limit to the emission you might receive from the spiral galaxy, and if so where is it and why? (30)

<u>**Condensed Matter Physics**</u>

In this problem you will be asked to discuss some properties of the reciprocal lattice of the trigonal Bravais lattice and verify special cases for the simple cubic (sc), the face-centered cubic (fcc), and the body-centered cubic (bcc) lattice, respectively. A trigonal Bravais lattice is generated by the primitive lattice vectors $\vec{a}_i$ for i=1,2,3 such that $\vec{a}_i \cdot \vec{a}_j = \begin{cases} c^2 \; for \quad i=j \\ c^2 \cos\theta \; for \quad i \neq j \end{cases}$, namely, the three primitive lattice vectors have equal magnitude, c, and angle, θ, between each other. What you need to do in this problem is to determine the reciprocal lattice vectors $\vec{b}_i$ and angle between them φ and discuss the magnitude $\left|\vec{b}_i\right|$ and angle φ for sc, fcc, and bcc lattice, respectively. The basic knowledge that you need to have is the primitive lattice (or basis) vectors, the reciprocal lattice vectors, and the lattice symmetry, such as the simple cubic (sc), the face-centered cubic (fcc), and the body-centered cubic (bcc) symmetries.

(a) The figure below shows (a) the simple cubic (sc), (b) the face-centered cubic (fcc), and the body-centered cubic (bcc) Bravais lattice, respectively. The solid circles represent points (or atoms) forming the lattice. Write down their primitive lattice vectors ($\vec{a}_1$, $\vec{a}_2$, and $\vec{a}_3$) (i.e., the bold arrows shown in the figure) in terms of the lattice constant a and the unit vectors ($\hat{i}$, $\hat{j}$, and $\hat{k}$) in Cartesian coordinates. Namely, you need to find the x, y, and z components for each vector, and express it as $\vec{a}_i = a_{ix}\hat{i} + a_{iy}\hat{j} + a_{iz}\hat{k}$, *i*=1,2,3. (15)

(b) The reciprocal lattice vectors are defined by

$$\vec{b}_i = 2\pi \frac{\vec{a}_j \times \vec{a}_k}{\vec{a}_1 \cdot \left(\vec{a}_2 \times \vec{a}_3\right)} \varepsilon_{ijk} \quad ;\varepsilon_{ijk} = \begin{cases} 1 \quad if\ ijk\ is\ an\ even\ permutation\ of\ x,y,z \\ -1 \quad if\ ijk\ is\ an\ odd\ permutation\ of\ x,y,z \\ 0 \quad if\ any\ two\ indeces\ among\ i,j,k\ are\ equal \end{cases}.$$

In the case of trigonal Bravais lattice, $\vec{a}_1 \cdot \left(\vec{a}_2 \times \vec{a}_3\right) = c^3 \sin^2\theta$. Please find the magnitude $\left|\vec{b}_i\right|$ and verify that $\left|\vec{b}_i\right|$ is the same for *i*=1, 2, 3. (15)

(c) Using the inner product of the trigonal Bravais lattice vectors (given in the introduction), prove that $\vec{b}_i \cdot \vec{b}_j = \dfrac{4\pi^2}{c^2 \sin^4\theta}\left(\cos^2\theta - \cos\theta\right) \quad for\ i \neq j$.
(**Hint**: $\left(\vec{C}\times\vec{D}\right)\cdot\left(\vec{E}\times\vec{F}\right) = \left(\vec{C}\cdot\vec{E}\right)\left(\vec{D}\cdot\vec{F}\right) - \left(\vec{C}\cdot\vec{F}\right)\left(\vec{D}\cdot\vec{E}\right)$). (20)

(d) Using the results from (b) and (c) to prove that $\cos\varphi = \dfrac{-\cos\theta}{1+\cos\theta}$, where φ is the angle between the reciprocal lattice vectors (**Hint:** $\vec{b}_i \cdot \vec{b}_j = \left|\vec{b}_i\right|^2 \cos\varphi$). (20)

(e) In the special three cubic lattices, i.e., the simple cubic (sc), the face-centered cubic (fcc), and the body-centered cubic (bcc) lattice, the values of θ are $\frac{\pi}{2}$, $\frac{\pi}{3}$, and 109.5°, respectively. Find the angle φ between the reciprocal lattice vectors for each of the three cubic lattices.

(30)

Figure (below): The three-dimensional lattices with (a) the sc symmetry, (b) the fcc symmetry, and (c) the bcc symmetry, respectively. The solid circles represent the points (or atoms) forming the lattice. The bold arrows are the primitive lattice vectors $\vec{a}_1$, $\vec{a}_2$, and $\vec{a}_3$. The black arrows denote the unit vectors ($\hat{i}$, $\hat{j}$, $\hat{k}$) of the Cartesian coordinates. The lattice constant (or the edge of the cubic) is indicated by *a*.