Homework for General Physics II, set7-Answers

1. **(Hecht’s 13.8)When the Sun’s spectrum is photographed, using rockets to range above the Earth’s atmosphere, it is found to have a peak in its spectral exitance at roughly 465nm. Compute the Sun’s surface temperature, assuming it to be a blackbody. This approximation yields a value that is about 400K too high.**

Answer:

Wien’s displacement law:

Wien’s law is not very accurate since the Sun is not exactly a blackbody and the emission is broad so that the peak position is not very accurate.

1. **(Hecht’s 13.10)(Same as Zhao’s book, problem 5,pg.275, I include the derivation in my pdf Slide used in class.）**

**The energy per unit area time per wavelength interval emitted by a blackbody at a temperature T is given by:**

**At a specific temperature, the total power radiated per unit area of the blackbody is equal to the area under the corresponding versus curve. Use this to derive the Stefan-Boltzmann Law.**

**[Hint: To clean up the exponential, change variables in the integral so that.**

**Use the fact that where the gamma function is given by And the Riemann zeta function for n=3 is.]**

Answer:

**Also estimate the Planck constant from the Stefan-Boltzmann constant σ= 5.67033× 10-8W/m2K4.**

Answer:

3. In blackbody radiation, I used  representing spectrum density of radiation power, where  is the radiation energy emitted by a unit area per unit time, at temperature T and within  around frequency ; We also use wavelength  as variable, , where  is the radiation energy emitted by a unit area per unit time, at temperature T and within  around . Prove that:

Answer:

 (the power emitted within small frequency interval is same as power emitted within corresponding small wavelength interval)

, 



4. This is a long problem which will derive the Planck formula of the spectrum energy density of the field, the energy per volume at certain T for frequency.

4-1. Einstein’ model of emission and absorption (this part is background information):

(Zhao’s fig. 3-4,Vol.2)

…………

Answer:



5. **The sodium (Na,** **23g/mol, density=0.97g/cm3)’s outer electron has work function of 2.36eV. We shine it with a light of 10-8W/m2. Assume you only know classical theory; use it to calculate how much** **time needed to produce a photoelectron with kinetic energy of 1 eV?**

**(Hint: You will need a couple simplified assumptions here. You want first** **estimate how many sodium atom per area. This can be done by assume one layer of atoms will absorb all the light. From the density, atomic weight and Avogadro number, you know the atoms per volume, and assume atoms are small cubes, you can estimate how many atoms in one layer. Assume the photo energy will all be absorbed and converted to outer shell electron’s energy with no other loss, and then you can get the answer, which would be on the order of 10 years)**

Answer:

The number of sodium atoms per volume:

The volume of one sodium atom:

Side length of a sodium atom cube:

The number of sodium atoms per layer and per area:

Time needed to produce a photoelectron with kinetic energy of 1 eV:

**6. In a photoelectric experiment (Milligan’s experiment) it is found that a stopping potential of 1.00eV is needed to stop all the electrons when the incident light of wavelength 260nm is used, and 2.30V is needed for the light of wavelength 207nm. From these data, estimate the Planck’s constant and the** **work function of the metal.**

Answer:

**7. If we are using 500nm visible light in the Compton experiment with free electrons (assume the initial speed of electrons is 0), at the 90 degree scattering angle, what is the *shift* of wavelength of the light at this angle?**

**(Hint: collisions between hard bodies)**

**What is the *energy loss* of the scattered light comparing with the input (in percentage comparing of the input)?**

**If the input light is 0.05nm X-ray, please answer the same questions above.**

**Can you think of an analogy in classical mechanics behaves at least qualitatively like this?**

Answer:

Answer:

Compton effect:



For 500nm light, at 90 degree , so 

 (for 500nm light) a very small percent.

For the 0.05nm X-ray, then same arguments:



In classical mechanics analogy (elastic collision between particles): visible light is like a small mass ping pong ball hitting a tank (electron), and during the collision there is little energy loss for the ping pong ball; while the X-ray with much higher energy is like a cannon ball hitting the tank and there will be noticeable energy transfer and thus energy change of the cannon ball.

**8. A photon with 40keV scatters from a free electron at rest. What is the maximum energy the electron can obtain? (Hint: The calculation is easy, do not try to use differentiation)**

Answer:

Maximum electron energy is obtained when the photon energy loss is the biggest. From the relation in compton’s effect, the scattered photon will have longest wavelength (lowest energy) when being scattered backward(180 degree), this is also intuitive from the conservation of momentum. .

The initial photo has energy of 40keV







9. Bohr’ s H atom: Below you need to find formula for orbit energy E，angular momentum L and radius of electron R in hydrogen (H) atom, using Bohr’s orbit model and de Broglie matter wave hypothesis:

Bohr proposed electron like a particle moves around nuclei in a **circular orbit** subject to Coulomb force. It has orbit radius R and energy E and angular momentum L to be determined. Using de Broglie matter wave, the longest wavelength can stably exist on the orbit with radius R must satisfy:  (A standing wave on a ring), and you may also know his famous relation between momentum and wavelength:  (SI unit). The Coulomb potential energy in hydrogen atom between electron an proton is: ,  (SI unit). Mass of electron is  (the reduced mass can be treated equal to this since proton is 1800 time massive).

1) Using the provided information, write the formula for possible (different n) L, R an E of the electron in H atom. ( Express L in h or ); and find out their minimum values (that is when n=1), express E in eV.

2) Ritz-Rydberg formula for transition frequency, when the electron changes from an initial orbit  to a final orbit (so called orbit quantum number), it emits out (or absorbs) light which satisfy Planck formula:  (Conservation of energy: , express the frequency of light with physical constant and orbit quantum numbers.

Answer:

There are a few ways to work this out (student can just use mv2/R=Force for circular motion; etc. , as in AB’s book), below I use the result derived from **central field problem**.

The problem already stated circular orbit and the following relation between R, E, L would be useful: (The results for Circular orbit we derived in Mechanics)



So different angular momentum, energy corresponds to different orbit radius.

L can be calculated from de Brodlie wavelength:

,  n=1,2,3

 (1)

The rest is just plug this into R, E relation:



Define (Bohr radius): , (2)

Then  (3)

, then for given Rn, the energy En:



Useful to assign:  (4)

 (5)

For lowest L, R, E (note: E1 is negative), they happen when n=1 (the lowest orbit number)







Above are all physical constants.

2) 

Now we know the expression for energy:

10.



Answer:

1) For electron moves in the n=1 circular orbit: R=

We know for n=1, angular momentum 





We learned in last problem: 

Then: 

Compare with the given formula of 

Clearly: 

b) Direct calculation and dimension analysis:  is a number with no unit, and its value is about 1/137 (This constant may worth remembering)

c) Compton wavelength: 

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