Physics 205 Syllabus, Fall, 1994

Instructor: Professor Marshall Onellion

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My office hours are Tuesday and Thursday mornings. I can also be reached by appointment. I often work at the Wisconsin Synchrotron Radiation Center, telephone 877-2200 or 877-2000. The receptionist will page me. You can leave a message on my voice mail at SRC, which is 877-2345.

We will cover the sections listed below of "Modern Physics" by P.A. Tipler. The material is listed based on having lectures (numbered) on Tuesdays and Thursdays: 1- 2.1, 2.2; 2- 2.3, 2.4; 3- 2.5, 2.6; 4- 3.1, 3.2; 5- 3.3, 3.4; 6- 3.5; 7- 3.6, 3.7; 8- 4.1, 4.2; 9- 4.3; 10- 4.4, 4.5; 11- 5.1, 5.2; 12- 5.3; 13- 5.4, 5.5; 14- 5.6 through 5.9; 15- 6.1, 6.2; 16- 6.3; 17- 6.4; 18- 6.6; 19- 6.7; 20- 6.8; 21- 7.1 through 7.3; 22- 7.4; 23- 7.5; 24- 7.6, 7.9; 25- 9.2; 26- 9.3; 27- 9.4; 28- 9.5; 29- 9.6, 9.7; 30- 9.8.

Homework will be assigned each Tuesday, due the following Tuesday in class. Homework solutions will be provided in class the same Tuesday that homework is turned in. The homework will be checked only for one thing: did you make a good faith effort? If so, regardless of whether your work is correct, you get a score of +1 on that problem. If not, you get a score of -1. The total homework score changes your overall score from between +5% to -5%. Since you cannot be assigned homework on the last week of class, I will provide a homework set- and solutions- at the last Tuesday class meeting, so that we can discuss the set the next Wednesday.

Each Wednesday, in discussion section, there is a 30 minute quiz. The quiz is on the homework you turned in the day before. The total quiz score is worth 25% of your overall score. Solutions will be provided, and your graded quizzes returned, the next day.

Physics 205
Professor Marshall Onellion

The class consists of two lectures and one discussion section each week. We will cover chapters two-six and, if there is time, chapter one of the text "Elementary Modern Physics," by Paul Tipler, Worth Publishers, New York, 1992. In addition to the text, I provide lecture notes for each lecture and discussion session. You are responsible for the contents of these lecture notes; I will assign homework, and draw examination problems, from the lecture notes.

Your grade will be determined by three equal parts, including homework and two examinations. The examinations are take home, open book and open library. Homework will be assigned at each lecture, due the following lecture. No late homework will be accepted. Six homework problems will be assigned and returned weekly, during the discussion section. Solutions to all homework will be provided during the discussion section at which your homework is returned. Both examinations will count equally. The final examination is cumulative, and will be given the last day of class, due at the time of the examination set by the registrare. There is a way to raise your grade (discussed below).

The average grade (before the way to raise your grade) will be between 2.2-2.6 (C=2.0). The way to raise your grade is to do the two additional, and more difficult, homework problems assigned each week in addition to the normal six. You can raise your class percentage by as much as 20% in this way. Example: Suppose you do all the extra homework, and get an average score of 50% on the extra homework. Suppose that your class average before the extra homework is 70%. Then your class percentage average will be raised from 70% to 70% + [20% x 0.5]= 80%. Since I will assign a percentage range for each grade before considering the effect of extra homework, you can raise your grade appreciably by this method. On the other hand, if you are doing very well, this will not hurt your grade, since your grade determined before the extra homework is considered would already be high.

Example: The class average is 75%. Your average is 95%. You get an A, regardless of who did what additional homework. However, suppose that your average is 75%, which would be a B/C. Then by raising your average to 95% (perfect score on additional homework), you get an A.

So what is the catch? On the regular homework, you can collaborate. On the additional homework, you are on your honor not to collaborate or to obtain assistance. I require that any additional homework you turn in include the following signed statement: "I have neither given nor received assistance on this additional homework." (Signature)

If you either give or receive assistance, then this is cheating and will be turned over to the university for disciplinary action.

My office hours are: Tuesday from class until 1 PM, Thursday from class until 11AM, and by appointment. Otherwise, you can reach me by electronic mail at: "monellion@wiscpsl.bitnet", or by calling 263-6829 (Madison campus) or 877-2200 (the synchrotron). I am often at the synchrotron, which is fifteen miles south of campus.

To aid us in determining whether you understand the lectures, a form will be given to each person at the end of each lecture. A given lecture will cover one or two ideas, no more. You will be asked what the idea(s) is, and whether you understand the idea. In this way, I get immediate feedback as to whether you understand.

Class lectures are at 8:50AM on Tuesday and Thursday, with discussion sections at 1:20PM and 2:25PM on Tuesday. The discussion sections will be used for review of homework and to cover additional lecture material.

Lecture One, September 2
Physics 205, Section 2.1 of text

The idea of this section is to understand the failure of classical physics to explain blackbody radiation, and the unexpected idea that lead to understand blackbody radiation. I am following R.M. Eisberg, "Fundamentals of Modern Physics," John Wiley and Sons, New York, 1961.

(1) Thinking of a black box as a standing wave source, the wavelengths components are: $\frac{\lambda_i}{2} = \frac{\lambda}{2\cos\theta_i}$; $i = x, y, z$.

(2) $E(x_i, t)$ = electric field components = $A\sin(2\pi x_i/\lambda_i)\ \sin(2\pi\nu t)$

(3) Which leads to boundary conditions: $\lambda_i = \left(\frac{n_i}{1}\right)(2x_i)$
$i = x, y, z$

(4) or: $\nu = \frac{c}{2a}\sqrt{n_x^2 + n_y^2 + n_z^2}$ a: size of box edge

(5) which leads to: $r = \sqrt{n_x^2 + n_y^2 + n_z^2} = \left(\frac{2a}{c}\right)\nu$

(6) leading to the number of allowed frequencies between ν and $\nu + d\nu$ as: $N(\nu)d\nu = \frac{4\pi a^3 \nu^2 d\nu}{c^3}$
c = speed of light

(7) The probability of having a state of energy ϵ is:
$P(\epsilon) = A\exp(-\epsilon/\epsilon_0)$; A and ϵ_0 constants

(8) The average energy $\bar{\epsilon} = \frac{\int_0^\infty \epsilon P(\epsilon)d\epsilon}{\int_0^\infty P(\epsilon)d\epsilon}$

(9) which leads to $\bar{\epsilon} = \epsilon_0$

(10) The equipartition theorem says that for a simple harmonic oscillator $\bar{\epsilon} = KT$; K = Boltzmann constant

(11) <u>or</u> $\epsilon_0 = KT$

12) and $P(\varepsilon) = A \exp\left(\frac{-\varepsilon}{KT}\right)$

(13) Energy density between ν and $\nu + d\nu$ is:

$$\rho(\nu)\,d\nu = \left(\frac{8\pi \nu^2 KT}{c^3}\right)d\nu$$

(14) Now $d\nu = -\frac{c\,d\lambda}{\lambda^2}$

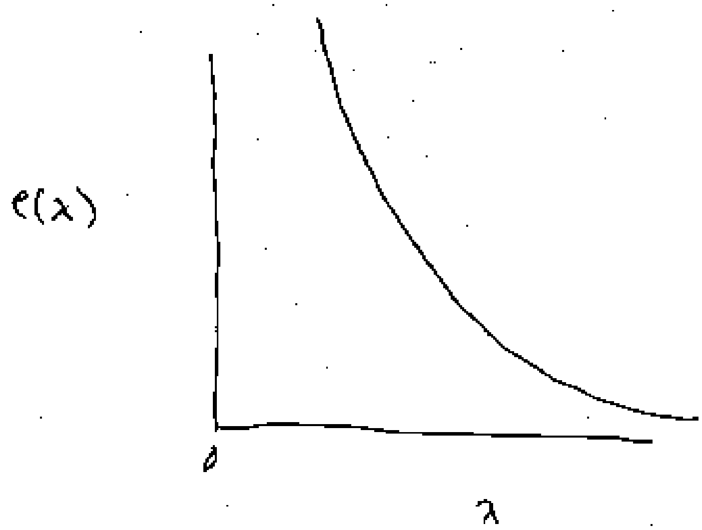
(15) or: $\rho(\lambda)\,d\lambda = -\rho(\nu)\,d\nu$

(16) or: $\rho(\lambda)\,d\lambda = \rho(\nu)\left(\frac{c\,d\nu}{\lambda^2}\right)$

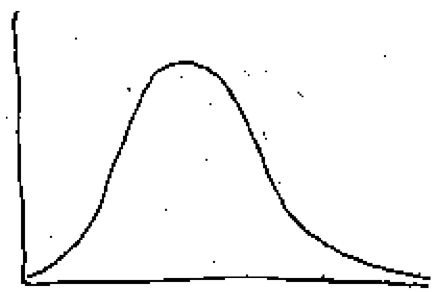
(17) or: $\rho(\lambda)\,d\lambda = \left(\frac{8\pi K}{\lambda^5}\right)(\lambda T)\,d\lambda$

Rayleigh-Jeans theory: Eisberg, 2-12 through 2-28

The result of this mathematics is a paradox. According to the theory, the amount of energy radiated by a black body increases without limit as the frequency of radiation increases. Experimentally, this would look like:



while the actual experiments yielded data that looked like:



Planck resolved this paradox by a radical assumption:
Any physical object that executes simple harmonic motion can possess only certain energies determined by the following equation:

(18) $\epsilon = n h \nu_0$

Eisberg, 2-29

where ν_0 is the fundamental frequency of oscillator, n is an integer and h is a universal constant (now called the Planck constant). Using this assumption, Planck calculated the spectral distribution function again:

$$\bar{\epsilon} = \frac{\sum_{n=0}^{\infty} \epsilon P(\epsilon)}{\sum_{n=0}^{\infty} P(\epsilon)} = \frac{\sum_{n=0}^{\infty} n h\nu e^{-\alpha n h\nu}}{\sum_{n=0}^{\infty} e^{-\alpha n h \nu}} \qquad \alpha = \frac{1}{KT}$$

$$= -\frac{d}{d\alpha} \ln\left[\sum_{n=0}^{\infty} e^{-\alpha n h\nu}\right] = -\frac{d}{d\alpha} \ln\left[(1 - e^{-\alpha h\nu})^{-1}\right]$$

$$= \frac{h\nu}{e^{h\nu/KT} - 1}$$

Lecture One, September 2
Physics 205, Section 2.1 of text

(19) So: $$\bar{\mathcal{E}} = \frac{h\nu}{\left[e^{h\nu/kT}-1\right]}$$

(20) or: $$\rho(\nu)d\nu = \left(\frac{8\pi\nu^2}{c^3}\right)\left(\frac{h\nu}{e^{h\nu/kT}-1}\right)d\nu$$

(21) or: $$\rho(\lambda)d\lambda = \left(\frac{8\pi hc}{\lambda^5}\right)\left(\frac{1}{e^{hc/\lambda kT}-1}\right)d\lambda$$

Eisberg, p. 65, and 2-30 through 2-32

Physically, the reason that the classical theory fails is that the classical theory assumes that there is always a continuum of energy levels. By establishing a minimum energy level, and all others are multiples thereof, Planck assured a cutoff in the spectral distribution function for high frequencies. The reason is that for $h\nu \gg kT$, only the lowest energy level (zero energy) is occupied with appreciable probability, so the expectation value of the amount of energy of such a high frequency is also zero. On the other hand, when $h\nu \ll kT$, the idea of a continuum of energy levels is valid, and the classical result is recovered.

Planck's explanation of black body radiation is, however, based on a radical assumption: not all energy levels are allowed.

Homework No. 1- due Sept. 14

Subsequent homework assignments will be due one week after assigned.

1. When the sun is directly overhead, the thermal energy incident upon the earth is approximately 1.4×10^6 erg-cm^{-2} -sec^{-1} . The diameter of the sun is about 1.6×10^{11} cm, and the distance from the sun to the earth is about 1.3×10^{13} cm.. Assume that the sun radiates as a black body, and estimate the surface temperature of the sum.

2. Starting with Planck's black body spectral distribution function, determine the total energy radiated in all frequencies per second per area from a surface of absolute temperature T. You should find that the total energy is proportional to some power of the temperature.

3. To a certain approximation, an atom of a crystal executes simple harmonic oscillations about its equilibrium position

because the atom possesses thermal energy and experiences an approximately linear restoring force. Find the bulk compressibility of iron (provide your reference) to estimate the strength of the restoring force and, from this, the oscillation frequency. Use the fact that the average total energy of a spring is kT to determine the oscillation energy at room temperature. Determine the approximate value of the quantum number that describes the motion of this microscopic simple harmonic oscillator. Is the quantum number representative of a microscopic or a macroscopic system?

4. You are given the job of determining the temperature of a vat of molten steel. You must know the temperature to within 10K. The temperature range can be between 2000-2600K. The vat is 3.0 meters in diameter and you must be able to scan across the surface of the molten steel to determine how uniform is the temperature. Using Planck's black body equation, or results that stem from it, tell me how you will do this, including:
(a) The general equipment to be used. Make a sketch of how you will install the equipment in relation to the vat. Hint: consider an optical technique;
(b) State specifically what the limitations on your accuracy are;
(c) Using the Thomas Register, give me an estimate of the cost of such a system;
(d) If- I emphasize if- you cannot know the temperature to within 10K, tell me the best you can do, and what the limitations are.

5. A salesman tell you that he has a revolutionary new method for determining the temperature of a silicon wafer, information essential for making 64Mbit memory chips. She says that the equipment determines the frequency where the Planck spectral distribution function is a maximum, and then uses this information to determine the temperature. You know secret information that your company heats the silicon to 750-790K during the fabrication process, and must know the temperature to within 5K. She says that his equipment is much less expensive, more reliable, etc. She also says that the resolving power of the equipment is 5000; the resolving power is the ratio between the wavelength measured and the spread in wavelengths admitted to the equipment. Finally, she says that the relative intensity can be measured to within 1%, and the absolute intensity to within 5%. Do you recommend purchase of this equipment? Explain the technical details of your decision.

6. Your laboratory partner says that, according to measurements done in a laboratory course while you were sick, 80% of the energy radiated from an object is between wavelengths of 200 nm and 800 nm. You realize that if this number (80%) is outside the range of 75-85%, you will fail this laboratory experiment. You have time to do the measurements yourself, but then not time to do this homework. Both ways of spending your time affect your

grade in the respective courses equally. **Do you repeat the measurements yourself, or not? Explain the technical details of your decision.**