Student ID Number: ________

PRELIMINARY EXAMINATION

DEPARTMENT OF PHYSICS

UNIVERSITY OF FLORIDA

Part D, January, 2018, 14:00–17:00

Instructions

1. You may use a calculator and CRC Math tables or equivalent. No other tables or aids are allowed or required. You may **NOT** use programmable calculators to store formulae.

   (a) All of the problems will be graded and will be tabulated to generate a final score. Therefore, you should submit work for all of the problems.

   (b) For convenience in grading please write legibly, use only one side of each sheet of paper, and work different problems on separate sheets of paper. The sheets for each problem will be stapled together but separately from the other two problems.

   (c) Your assigned student **ID Number**, the **Problem Number**, and the **Page Number** should appear in the upper right hand corner of each sheet. Do **NOT** use your name anywhere on the Exam.

   (d) All work must be shown to receive full credit. Work must be clear and unambiguous. Be sure that you hand your completed work to the Proctor.

   (e) Each problem is worth 10 points.

   (f) Following the UF Honor Code, your work on this examination must reflect your own independent effort, and you must not have given, nor received, any unauthorized help or assistance. If you have any questions, ask the Proctor.

University of Florida Honor Code: We, the members of the University of Florida community, pledge to hold ourselves and our peers to the highest standards of honesty and integrity. On all work submitted for credit by students at the University of Florida, the following pledge is either required or implied: *"On my honor, I have neither given nor received unauthorized aid in doing this assignment."*

DO NOT OPEN EXAM UNTIL INSTRUCTED

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D1. **(Sullivan)** Consider an ensemble of N magnetic ions in a lattice that have a magnetic moment μ and spin $\frac{1}{2}$. If the ensemble is placed in a magnetic field B and if the ions do not interact with each other

(a) [**1 point**] What are the possible energy levels of each ion?

(b) [**1 point**] Write down an expression for the partition function for the N ions at temperature T.

(c) [**3 points**] Write down an expression for the free energy F.

(d) [**3 points**] Show that the entropy can be written as

$$S = Nk_B \left[\ln(1 + e^{-2x}) + 2x \frac{e^{-2x}}{1 + e^{-2x}} \right]$$

where $x = \frac{\mu B}{k_B T}$.

(e) [**2 points**] If the ions are magnetized in afield of $B = 10$ tesla at $0.1K$ and then in an adiabatic process the magnetic field is reversibly reduced to 0.10 tesla, what is is the final temperature of the spins?

D2. **(Hebard)** The Lorentzian $\mathcal{L}(\nu, \nu_0)$ describes the line shape of transition processes involving atoms and laser fields. The three main processes are stimulated absorption, stimulated emission and spontaneous emission. The frequency dependence of these processes has a "Lorentzian" line shape characterized by the energy envelope of a lightly damped driven harmonic oscillator described by the equation:

$$\ddot{x} + \gamma\dot{x} + \omega_0^2 x = F(t)/m = f(t) = f_0\cos(\omega t) = f_0\Re[e^{i\omega t}] \tag{1}$$

Here $x(t)$ is the displacement from equilibrium of a mass m driven by an oscillating external force $F(t) = F_0\Re[e^{i\omega t}] = F_0\cos(\omega t)$ with amplitude $F_0 = mf_0$ and frequency ω. Equation 1 when multiplied by m reveals the underlying force balance equation $m\ddot{x} = F(t) - m\gamma\dot{x} - kx$ where the restoring force constant $k = m\omega_0^2$ with ω_0 the natural frequency of oscillation (free oscillation with no damping) and $-m\gamma\dot{x}$ is the damping force linear in velocity and proportional to a damping constant γ in frequency (Hz) units.

(a) [**4 points**] Insert the trial solution

$$x(t) = A(\omega)\cos(\omega t + \delta) = \Re[Ae^{i(\omega t+\delta)}] \tag{2}$$

into Eq. 1 and find expressions for the amplitude $A(\omega)$ and phase $\delta(\omega)$. Hint, it is easiest to work with complex variables where you start with the solution $x(t) = \tilde{A}e^{i(\omega t+\delta)}$. Your answers should be in terms of ω, ω_0, γ and f_0 and you should assume that all transients have died out.

(b) [**1 point**] For weak damping sketch $A(\omega)$ and $\delta(\omega)$ and state whether the phase of the displacement leads or lags the phase of the driving force. In all sketches identify your axes and label prominent features.

(c) [**2 points**] Derive an expression for the time average $< E >$ of the sum of the kinetic and potential energies using the periodic solution of Eq. 2 and the results of Part (1) above. Again your answer should involve the parameters ω, ω_0, γ and f_0.

(d) [**2 points**] Assume a small damping constant γ, or equivalently a high Q or long lifetime, and derive an expression for $< E >$ (using reasonable approximations) which when plotted against frequency becomes sharply peaked and symmetric with respect to a characteristic peak frequency which you should identify.

(e) **[1 point]** Sketch your result with both the peak frequency and the full width half maximum (FWHM) identified. Label all prominent features and compare this result with your sketch in Part 2.

In this exercise you have found the "universal" commonly observed Lorentzian lineshape for long lifetime states and sharply tuned resonances with the form $< E >=$ prefactor $*$ $\mathcal{L}(\omega, \omega_{\text{peak}}, \gamma)$ where $\mathcal{L}$ is normalized to unity at a peak frequency ω_{peak} and a FWHM related to γ, both of which you have identified and related to the properties of lightly damped harmonic oscillators.

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D3. **(Rinzler)** A laser ablation system uses two 1064 nm wavelength Q-switched pulsed lasers that each output 500 millijoule pulses in 9 ns at a rate of 10 Hz.

(a) [**1 point**] What is the average power from each laser?

(b) [**1 point**] What is the approximate peak power of each laser?

The optimum ablation from the target happens when the lasers are fired with the second laser pulse following the first by 40 ns. The laser manufacturer provides both a Q-switch trigger output and a Q-switch trigger input. The latter with an adjustable delay so you can adjust the timing between the pulses from near zero to 200 ns, but the delay is not calibrated so you must monitor the pulses to set the proper delay.

(c) [**1 point**] You have on hand a silicon pin photodiode. The bandgap of Si is 1.1 eV. Will this be sensitive to the 1064 nm radiation of the lasers? If no by what fraction of an eV is the laser wavelength short, if yes by what fraction of an eV does the laser wavelength exceed the bandgap? (Some constants and conversions you may find useful: h = $6.626 \times 10^{-34} m^2 kg/s$; c = 2.998×10^8 m/s ; 1 eV = 1.602×10^{-19} J)

(d) [**1 point**] Either with this or another appropriate detector sketch an experimental arrangement for the measurement showing the location of the detector, the lasers, the beams, and any optical elements you elect to use.

(e) [**1 point**] Supposing that the Si pin photodiode will work. Draw a crude sketch of the flat band diagram of the p, i and n layers. This should show, for each of the layers (before they are placed into contact) the Fermi level, the valence band edge and the conduction band edge in approximate relation to each other. Label each layer showing the Fermi levels, band gap and band edges.

(f) [**1 point**] When the layers of part (e) are placed into contact there is a charge exchange that results in electric potentials typically represented in a band bending across the junctions formed. Draw an approximate sketch that reflects the shifts in the flat band energy levels and band bending (Hint: think Fermi level equilibration).

(g) [**1 point**] pin photodiodes are used in so called reverse bias. Sketch the effect on the bands when the reverse bias is applied. (Hint: positive bias shifts levels downwards relative to the vacuum level.)

(h) **[1 point]** for making the measurement you have available a 1 GHz bandwidth storage oscilloscope and a 100MHz storage oscilloscope. The input for each scope says 1 MΩ and 20pF. Which do you choose and why?

(i) **[2 points]** You power the photodiode with a 3V battery and connect it to the scope using 3 ft. of RG-231A/U coaxial cable (capacitance 25 pF/ft), as shown in the sketch below. With this set-up rather than seeing two 10 ns pulses you measure one long exponentially decaying pulse of 95 μs! You puzzle over this a bit before realizing your error for which there is a very simple fix. What is that fix? (Hint: think about the input resistance for the scope, how the capacitances involved combine, and realize that, i) you have lots of signal strength, and ii) you have at your disposal a variety of resistors, from 50Ω to 10MΩ along with the ability to wire these in, however might be productive).