Name: ______________________________ 100 points **Show all work.**

1. (10) You expose an unknown microscopic system to electromagnetic radiation, and you measure the absorption spectrum — which frequencies get absorbed by the system and which do not. What specific features of this spectrum will you use to decide whether your system is a harmonic oscillator, a hydrogen atom, or something else altogether? Explain.

2. (10) Describe one experiment that demonstrates the existence of spin angular momentum. Explain the demonstration.

3. (10) An electron has speed 3.00×10^6 m/s in the lab, with a 1% uncertainty in its momentum. Evaluate (a) the minimum uncertainty in the position of the electron, and (b) the de Broglie wavelength of the electron. Would this electron be better suited to probe the inner structure of an atom or of a proton? Explain.

4. (10) Λ° particles are produced at a target, and are all directed toward a detector 2.00 m away. Evaluate the minimum speed v of the Λ°s in that laboratory such that at least half of them arrive at the detector. Report your answer as $c - v$, where c is the speed of light. *Recall that the half-life is the mean lifetime times* $\ln(2)$.

5. (10) Particle X decays into two charged pions: $X \to \pi^+ + \pi^-$. One pion has kinetic energy 282 MeV and moves in the $+x$ direction; the other has kinetic energy 25.0 MeV and moves in the $-x$ direction. Explain how we know that X was not at rest prior to the decay. Evaluate the rest energy of particle X.

6. A particle of mass m is subject to a potential energy $U(x)$. The system has certain energy E is described by a one-dimensional wave function

$$\psi(x) = \begin{cases} 0 & \text{for } \; x < 0 \\ C\,x\,e^{-bx} & \text{for } \; x > 0 \end{cases}, \quad \text{with real constants } C > 0 \text{ and } b > 0.$$

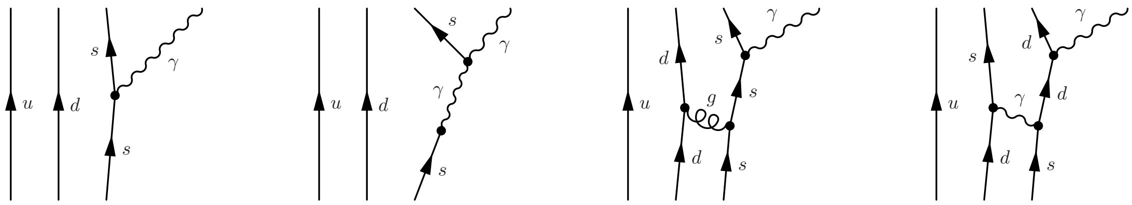
(a) (10) Sketch the probability density, indicating estimates of the values of the expectation value of the location of the particle and its associated uncertainty.

Explain how you are making the plot. *Remember that graphing calculators are prohibited.*

(b) (10) Determine the energy E and $U(x)$ for this system.

7. Consider the decay $\Sigma^0 \to \Lambda^0 + \gamma$.

(a) (10) Classify each of the following Feynman diagrams is as either valid or invalid. For each invalid diagram, explain why. Time increases toward the top of the page.



(b) (10) If all of the angular momentum initially comes from the spin of the Σ^0, what are the possible values of the angular momentum quantum number ℓ after the decay?

(c) (10) Is $\Sigma^0 \to \Sigma^+ + e^- + \bar{\nu}_e$ also a possible decay mode? If so, explain which interaction is responsible. If not, explain why not.

$c = 2.998 \times 10^8$ m/s	$e = 1.602 \times 10^{-19}$ C	1 eV $= 1.602 \times 10^{-19}$ J
$h = 6.626 \times 10^{-34}$ J · s	$hc = 1240$ eV · nm	$\lambda_m T = 2.898 \times 10^{-3}$ m · K
$k = 8.617 \times 10^{-5}$ eV/K	$\sigma = 5.670 \times 10^{-8}$ W/m^2 · K^4	$\lambda_m V = 1240$ nm · V
$R_\infty = 1.097373 \times 10^7$ m^{-1}	$\alpha \approx 1/137$	1 u $= 931.494$ MeV/c^2
$E_\circ = 13.6$ eV	$a_\circ = 0.0529$ nm	$\hbar = h/(2\pi)$

Particle	Lepton Number L_e	L_μ	L_τ	Mass (MeV/c^2)	Mean Life (s)
e^-	1	0	0	0.510998910	Stable
ν_e	1	0	0	$< 3 \times 10^{-6}$	Stable
μ^-	0	1	0	105.658367	2.197034×10^{-6}
ν_μ	0	1	0	< 0.19	Stable
τ^-	0	0	1	1776.82	290.6×10^{-15}
ν_τ	0	0	1	< 18	Stable

All leptons and quarks are spin one-half particles.

Quark	Mass (MeV/c^2)	Charge (e)	Baryon Number	U	D	S	C	B	T
u	1.7–3.3	$+\frac{2}{3}$	$\frac{1}{3}$	+1	0	0	0	0	0
d	4.1–5.8	$-\frac{1}{3}$	$\frac{1}{3}$	0	-1	0	0	0	0
s	80–130	$-\frac{1}{3}$	$\frac{1}{3}$	0	0	-1	0	0	0
c	1180–1340	$+\frac{2}{3}$	$\frac{1}{3}$	0	0	0	+1	0	0
b	4130–4850	$-\frac{1}{3}$	$\frac{1}{3}$	0	0	0	0	-1	0
t	172.0×10^3	$+\frac{2}{3}$	$\frac{1}{3}$	0	0	0	0	0	+1

Particle	Baryon Number	Spin	Strange-ness	Quark Content	Mass (MeV/c^2)	Mean Life (s)
π^+	0	0	0	$u\bar{d}$	140	2.6×10^{-8}
π°	0	0	0	$u\bar{u}, d\bar{d}$	135	8.4×10^{-17}
η	0	0	0	$u\bar{u}, d\bar{d}$	547	5.6×10^{-19}
K^+	0	0	+1	$u\bar{s}$	494	1.2×10^{-8}
K°	0	0	+1	$d\bar{s}$	498	8.9×10^{-11}
					5.2×10^{-8}	
p	1	$\frac{1}{2}$	0	uud	938.272013	Stable
n	1	$\frac{1}{2}$	0	udd	939.565346	885.7
Δ^{++}	1	$\frac{3}{2}$	0	uuu	1232	5.5×10^{-24}
Δ^+	1	$\frac{3}{2}$	0	uud	1232	5.5×10^{-24}
Δ°	1	$\frac{3}{2}$	0	udd	1232	5.5×10^{-24}
Δ^-	1	$\frac{3}{2}$	0	ddd	1232	5.5×10^{-24}
Λ°	1	$\frac{1}{2}$	-1	uds	1115.683	2.631×10^{-10}
Σ^+	1	$\frac{1}{2}$	-1	uus	1189.37	0.8018×10^{-10}
Σ°	1	$\frac{1}{2}$	-1	uds	1192.642	7.4×10^{-20}
Σ^-	1	$\frac{1}{2}$	-1	dds	1197.449	1.479×10^{-10}
Ξ°	1	$\frac{1}{2}$	-2	uss	1314.86	2.90×10^{-10}
Ξ^-	1	$\frac{1}{2}$	-2	dss	1321.71	1.639×10^{-10}
Ω^-	1	$\frac{3}{2}$	-3	sss	1672.45	0.821×10^{-10}