Name ___________________

Solutions to Final Exam

Part I: Multiple Choice (mixed new and review questions) [50 points]
For each question, choose the best answer (2 points each)

1. The following masses are listed in the book as masses of some of the isotopes of Mg. Which one is clearly a misprint?
   A) 22.994124 u
   B) 23.985042 u ← Due to a typo on the test, this was accepted as well
   C) 26.985838 u
   D) 27.984341 u
   E) 28.375346 u

2. When calculations were done for the amount of energy density in a thermal background of electromagnetic energy, the result, before quantum theory was developed, was
   A) Zero
   B) A non-zero amount, but less than the experimental value
   C) Exactly the right amount, but at the wrong wavelengths
   D) A finite amount, but more than the experimental values
   E) Infinity

3. Which of the following is *not* consistent with special relativity?
   A) Time is the fourth dimension
   B) It is always possible to tell which of two objects is actually moving based on how fast their clocks are running compared to each other
   C) Which of two events occurred first may be disagreed on by different observers
   D) There are no truly rigid objects in special relativity
   E) Objects moving at high speed appear to be shorter, as viewed by stationary observers

4. According to the Bohr model (and current quantum mechanics), the reason that only certain wavelengths come out of atoms like hydrogen is because
   A) The electrons can only exist at certain energy levels; the differences in energy determine the wavelengths of light that come out
   B) The atoms have a particular size, and only certain wavelengths of light will fit inside those atoms
   C) The multiple electrons in the atoms are spaced at precisely those wavelengths, and they radiate together to make the wave
   D) The electrons orbit at exactly the corresponding frequencies, so that's the frequencies that come out
   E) The electrons themselves have that wavelength, and coherently generate only those wavelengths
5. One observation that helped lead Einstein to the general theory of relativity was that

A) Heavy objects fall slightly faster than light objects
B) Objects in gravitational fields move in curved lines; other forces cause them to move in straight lines
C) Gravity always causes the velocity of objects to be downwards
D) Objects should be able to produce gravity waves, but in Newton's theory, they cannot
E) The effects of gravity are indistinguishable from the effects of being in an accelerated reference frame

6. In β^+-decay, what particle comes out of a nucleus, besides a neutrino?
A) A ^{4}He nucleus
B) An electron
C) A proton
D) An anti-electron, also called a positron
E) A neutron

7. If I tell you are looking at a 5p electron, I mean that
A) $n = 5$ and $l = 3$
B) $n = 3$ and $l = 5$
C) $n = 5$ and $l = 1$
D) $n = 1$ and $l = 5$
E) $n = 5$ and $l = 5$

8. When you get near a massive object, according to general relativity,
A) Time runs at a constant rate, even if you are moving
B) Time depends on the mass, not just the speed, of the observer
C) Time speeds up
D) Time slows down
E) Time runs in reverse

9. If two objects are moving towards each other, each moving at 2/3 the speed of light, then as viewed by one of them, the other one will be moving
A) Faster than the speed of light (definitely)
B) Slower than the speed of light (definitely)
C) At the speed of light (definitely)
D) Either faster or slower, depending on which person is actually moving
E) There is insufficient information to answer this question

10. If q stands for a quark, and $\bar{q}$ stands for an anti-quark, which combination does not seem to occur in nature?
A) qqq B) $\overline{qqq}$ C) $\bar{q}q$ **D) $\bar{q}qq$** E) Actually, these all <u>do</u> occur in nature

11. What is the stress-energy tensor $T_{\mu\nu}$ that is described in general relativity?

A) It represents the gravitational force on some object
B) It contains the energy density, momentum density, and other quantities that cause spacetime curvature
C) It contains the energy density, but none of the other quantities, that cause spacetime curvature
D) It describes the curvature of spacetime
E) It describes the distance formula in curved spacetime

12. Momentum has three components, but in four dimensions, it becomes a four-dimensional vector whose fourth component is closely related to
A) time B) velocity C) mass D) angular momentum **E) energy**

13. Which of the following is not a condition that the wave function $\psi(x,t)$ must satisfy, in general?
A) It must be continuous
B) It must be finite
C) It must have a continuous derivative, if the potential energy is finite
D) It must fall off to zero at infinity
E) It must be real

14. What is the name of the isotope that contains 18 neutrons and 17 protons?
A) ^{18}Cl B) ^{17}Cl **C) ^{35}Cl** D) ^{17}Ar E) ^{35}Ar

15. The basic reason that heavy nuclei (like Uranium) have more neutrons than protons is because
A) The positively charged protons don't like to be near each other; neutrons don't mind being near each other
B) The strong force is slightly stronger between neutrons than it is between protons
C) The neutron is a little heavier than the proton
D) There are so many electrons around that a few protons are bound to capture some and become neutrons
E) Protons must obey the Pauli exclusion principle; neutrons need not

16. DeBroglie found there was a direct relationship between the wavelength of a wave and the ___________ of a particle
A) energy B) mass C) frequency **D) momentum** E) velocity

17. What is the meaning of the *group velocity* of a wave?
A) It is how fast an individual peak of a wave moves
B) It is how fast an individual trough of a wave moves
C) It is how fast the wave, as a whole, moves
D) It is how fast the frequency changes
E) It is how fast the wavelength changes

18. There are a pair of neutron stars that are orbiting each other. Observations indicate that the two stars are slowly moving closer together. The reason is that

A) Friction caused by rubbing against the bumpy metric (distance formula) causes them to slow down and gradually spiral towards each other
B) Orbits in general relativity are not ellipses, but rather spirals that very slowly bring the two objects together
C) Gravity waves are emitted by the pair of neutron stars, draining energy from the system
D) Gravitational flux tubes connecting the pair gradually pull them together
E) The moving together is an illusion caused by the relativistic velocities, making the distance seem to shrink due to Lorentz contraction

In questions 19-21, you will answer questions about a particle made of an up quark and strange anti-quark, [$u\bar{s}$ **]**

19. What type of particle is made of [$u\bar{s}$]?
A) lepton B) anti-lepton **C) meson** D) baryon E) anti-baryon

20. The charge of the particle made from [$u\bar{s}$] is
A) -1 B) -1/3 C) 0 D) +1/3 **E) +1**

21. The strangeness of the particle [$u\bar{s}$] is
A) -2 B) -1 C) 0 **D) +1** E) +2

In questions 22 – 25, you will be given a reaction, and you must state what type of interaction it is. A mimi-table of particles is listed at right. **<u>All of them have spin ½ and strangeness 0.</u>**

22. $\mu^+ + \mu^- \rightarrow$ photon + photon (the μ^+ is the anti-particle of the μ^-)
A) impossible B) strong C) weak **D) electromagnetic** E) gravity

23. $n^0 + \nu_\mu \rightarrow p^+ + \mu^-$
A) impossible B) strong **C) weak** D) electromagnetic E) gravity

24. $n^0 + \bar{n}^0 \rightarrow p^+ + \bar{p}^-$ (the $\bar{n}^0$ and $\bar{p}^-$ are the anti-particles of the n^0 and p^+)
A) impossible **B) strong** C) weak D) electromagnetic E) gravity

25. $\mu^- + \mu^- \rightarrow$ photon + photon
A) impossible B) strong C) weak D) electromagnetic E) gravity

Baryons	
<u>Name</u>	<u>Mass</u>
p^+	938
n^0	940
Leptons	
<u>Name</u>	<u>Mass</u>
μ^-	106
ν_μ	0
Other	
<u>Name</u>	<u>Mass</u>
photon	0

Part II: Short answer (review material) [20 points]

Choose **two** of the following three questions and give a short answer (1-3 sentences) (10 points each).

26. In the twin paradox, one twin stays on Earth while the other travels around in space, eventually returning to Earth. Which one is younger, if either, and explain how it makes sense to know which one is "really" moving.

The twin who travels through space will be younger. This is apparently a paradox because it seems that it is impossible to describe which of the twins is "really" moving. The paradox is resolved when you realize that the traveling twin is really accelerating, and therefore it is taking a shorter proper time path through spacetime.

27. Explain, using the uncertainty principle, why an electron in an atom doesn't just go to the nucleus at the origin, but instead is spread out.

In classical mechanics, the electron would tend to go right to the nucleus. In quantum mechanics, if you were to specify the particle's position that precisely, then the small uncertainty in the position would cause a large uncertainty in the momentum. This means it has a lot of momentum, and therefore a lot of energy. Instead of shrinking to zero, it ends up spread out.

28. A hydrogen atom is described by four quantum numbers: the energy value n, the total angular momentum l, the z-component of the angular momentum m, and the z-component of the spin m_s. Suppose these take the values –2, +½, 2, and 4, <u>not respectively</u>. Which one is which, *i.e.*, which of these is n, l, m, and m_s?

The quantum number n is a positive integer that is larger than the non-negative integer l. This tells us that we must have $n = 4$, and also $l = 2$. Then we know m is an integer and m_s is ±½, so we must have $m = -2$ and $m_s = ½$.

$n = 4$ $l = 2$ $m = -2$ $m_s = ½$.

Part III: Short answer (new material) [30 points]

Choose **three** of the following four questions and give a short answer (1-3 sentences) (10 points each).

29. There is an atom whose electrons take the configuration

$$1s^2\ 2s^2\ 2p^6\ 3s2\ 3p^6\ 4s^1\ 3d^5$$

What type of atom is this? According to the rules we talked about in class, what *should* the electronic configuration be?

The total number of electrons is 24, so this is a Chromium atom. According to the rules given in class, this is the correct order to fill up the shells, but one should fill up a shell before proceeding to the next one, so we should have $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^5$ instead.

30. Explain, qualitatively, why most stable nuclei have approximately equal numbers of protons and neutrons.

Just like electrons in an atom, nuclei have shells, each shell having more energy than the shell beneath it. When you put nucleons in, they will fill up the lowest energy shells, then the next level, and so on. However, because protons and neutrons are different particles, they each have their own sets of shells. If the numbers were highly disparate, the proton could become a neutron and drop to a lower energy shell, or vice versa.

31. What are the names of the six quarks in the standard model of particle physics? Give the electric charges of at least two of them.

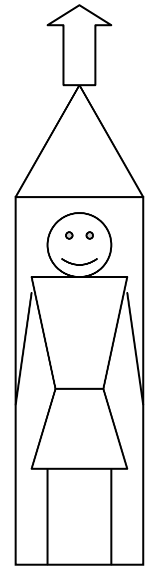
The quarks are the up, down, strange, charm, top, and bottom quarks. The up, charm, and top quarks have charge +2/3; the down, strange, and bottom quarks have charge -1/3.

32. Explain how the orbit of a planet like Mercury differs, according to general relativity, from the predictions of Newton's theory of gravity.

In Newton's theory of gravity, planets move in an ellipse. In general relativity, they *almost* move in a perfect ellipse, but the direction of the long axis slowly precesses over time.

Part IV: Calculation (review material) [40 points]

Choose **two** of the following three questions and perform the indicated calculations (20 points each)



33. A woman who has just become pregnant has a mass of 69.0 kg. She gets aboard a spacecraft traveling at a velocity of 2.9×10⁸ m/s.

(a) What is her total energy *E*, as measured by us?

We start by calculating the Lorentz factor, given by

$$\gamma = \frac{1}{\sqrt{1-v^2/c^2}} = \frac{1}{\sqrt{1-\left(2.900\times10^8\text{ m/s}\right)^2/\left(2.998\times10^8\text{ m/s}\right)^2}} = 3.94.$$

We then use the formula for total energy, namely

$$E = \gamma mc^2 = 3.94\left(69.0\text{ kg}\right)\left(2.998\times10^8\text{ m/s}\right)^2 = 2.45\times10^{19}\text{ J}.$$

(b) Assuming her baby takes the usual 0.75 years to gestate, as measured by her, how long will it be until the baby is born, according to us?

Time runs more slowly for her, so our time is related to her time by $\Delta t = \gamma\tau$, so

$$\Delta t = \gamma\tau = \left(3.92\right)\left(0.75\text{ yr}\right) = 2.96\text{ yr}.$$

(c) How far will she have traveled in this amount of time? 1 year = 3.15×10⁷ s.

This would be most easily worked out in light years, but let's do it in meters.

$$d = vt = \left(2.90\times10^8\text{ m/s}\right)\left(2.96\text{ yr}\right)\left(3.155\times10^7\text{ s/yr}\right) = 2.71\times10^{16}\text{ m}.$$

(d) The woman is 169 cm tall and measures 92 cm around her hips. What are the same two measurements, according to observers on the Earth? The rocket is traveling in the direction of her height.

Because she is moving so quickly, she will be Lorentz contracted in the direction she is moving. Hence her measured length will be

$$L = L_p/\gamma = \left(169\text{ cm}\right)/3.94 = 42.9\text{ cm}$$

Because there is no Lorentz contraction in the horizontal direction, she will still be 92 cm around at the hips.

34. A photon with wavelength 297 nm strikes a metal plate. Electrons are observed to be emitted from the metal plate, provided they are not faced with an electrostatic barrier of more than 0.613 V.

(a) What is the frequency of the photons? What is the corresponding energy of the photons?

To find the frequency, we simply use the formula $f\lambda = c$ so we have

$$f = c/\lambda = \left(2.998\times10^{8}\text{ m/s}\right)\big/\left(297\times10^{-9}\text{ m}\right) = 1.009\times10^{15}\text{ Hz.}$$

The energy of the photons is then found using $E = hf$.

$$E = hf = \left(4.136\times10^{-15}\text{ eV}\cdot\text{s}\right)\left(1.009\times10^{15}\text{ s}^{-1}\right) = 4.173\text{ eV.}$$

(b) What is the work function for this metal?

The energy of the photon goes into liberating the electron, with any left over energy appearing as kinetic energy of the electron. This kinetic energy can then overcome the electrostatic barrier, provided it is greater than it. If ϕ is the amount of work required to free the electron, then $eV_{\text{max}} = hf - \phi$, or solving for ϕ, we have

$$\phi = hf - eV_{\text{max}} = 4.173\text{ eV} - 0.613\text{ eV} = 3.560\text{ eV.}$$

(c) Explain qualitatively what would happen if the intensity of the light were cut down substantially.

Since the energy of each photon is the same, no matter the intensity, the only effect of cutting down the intensity will be that there are fewer photons, and therefore, there will be fewer electrons coming loose. But there will be no delay in when the first electrons come out.

(d) Explain qualitatively what would happen if the frequency of the light were cut down substantially.

More than 80% of the energy of the photon is going to free the electron. Any significant reduction in the frequency would make them have insufficient energy to free *any* electrons, and no electrons would be freed.

35. A particle has a wave function given by

$$\psi(x) = \begin{cases} \sqrt{2/a}\cos(\pi x/a) & \text{if } |x| < \tfrac{1}{2}a \\ 0 & \text{otherwise.} \end{cases}$$

(a) What is the most likely place to find the particle?

The most likely place to find the particle is where the wave function is at a maximum. To find this point, we simply take the derivative and set it equal to zero.

$$0 = \frac{d\psi(x)}{dx} = \frac{a}{\pi}\sqrt{\frac{2}{a}}\sin\left(\frac{\pi x}{a}\right)$$

The only place this vanishes in the range under consideration is at $x = 0$, so this is where the wave function is maximized.

(b) If the position of the particle is measured, what is the probability that it will be found at $0 < x < \tfrac{1}{6}a$. Some possibly useful formulas can be found below.

The probability of finding the particle in a given range is just the square of the amplitude integrated over that region, so

$$\begin{aligned} P\left(0 < x < \tfrac{1}{6}a\right) &= (2/a)\int_0^{a/6}\cos^2(\pi x/a)\,dx = (2/a)\left[x/2 + a\sin(2\pi x/a)/4\pi\right]_0^{a/6} \\ &= (2/a)\left[a/12 + a\sin(2\pi a/6a)/4\pi\right] = \tfrac{1}{6} + \tfrac{1}{2\pi}\sin\left(\tfrac{1}{3}\pi\right) = \tfrac{1}{6} + \tfrac{\sqrt{3}}{4\pi}. \end{aligned}$$

So the probability is about 30.45%.

$$\int\cos(Ax)\,dx = \sin(Ax)/A, \qquad \int\cos^2(Ax)\,dx = x/2 + \sin(2AX)/4A,$$

$$\cos(0) = \sin\left(\tfrac{1}{2}\pi\right) = 1, \qquad \cos\left(\tfrac{1}{3}\pi\right) = \sin\left(\tfrac{1}{6}\pi\right) = \tfrac{1}{2},$$

$$\cos\left(\tfrac{1}{2}\pi\right) = \sin(0) = 0, \qquad \cos\left(\tfrac{1}{6}\pi\right) = \sin\left(\tfrac{1}{3}\pi\right) = \tfrac{\sqrt{3}}{2}.$$

Part V: Calculation (new material): [60 points]

Choose **three** of the following four questions and perform the indicated calculations (20 points each)

36. Thermonuclear weapons contain the radioactive isotope ^{3}H, which has a half-life of 12.33 years and an atomic mass of 3.016 u.

(a) What is the decay rate λ for this isotope?

The decay rate is simply given by

$$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.692}{12.33\text{ yr}} = 0.05622\text{ yr}^{-1}$$

(b) If I have one gram of ^{3}H, how many atoms do I have?

We simply divide the mass by the mass of one atom, which yields

$$N = \frac{1\text{ g}}{3.016\text{ u}} = \frac{N_A}{3.016} = \frac{6.022\times10^{23}}{3.016} = 1.997\times10^{23}$$

(c) What is the rate of decay for one gram of ^{3}H? You may leave your answer in decays/year, if you want.

We use the formula $R = \lambda N$ to give

$$R = \lambda N = \left(0.055\text{ yr}^{-1}\right)\left(1.996\times10^{23}\right) = 1.122\times10^{22}\text{ yr}^{-1} = 3.557\times10^{14}\text{ s}^{-1}$$

(d) How long do we have to wait before that 1 g of ^{3}H becomes 0.1 g of ^{3}H, due to radioactive decay?

The mass is obviously proportional to the number of atoms. Hence this is the same as asking how long before the number of atoms is reduced by a factor of 10. Hence we have

$$\frac{N}{N_0} = 0.1 \qquad \text{where} \qquad N = N_0 e^{-\lambda t}.$$

This gives us

$$0.1 = \frac{N}{N_0} = e^{-\lambda t},$$

$$\ln(0.1) = -\lambda t,$$

$$t = -\frac{\ln(0.1)}{\lambda} = \frac{2.303}{0.05622\text{ yr}^{-1}} = 40.96\text{ yr.}$$

37. Photocopied with the equation on the next page is a portion of Appendix A from the text. ^{50}V is an unstable nucleus which may have multiple decay modes.

(a) What would be the resulting isotope if this isotope underwent β^- decay? What if it underwent electron capture? What if it underwent α-decay?

We start with ^{50}V, which has Z = 23, and a mass of 49.947161 u. Under β^- decay, Z would increase by one to Z = 24, while A would stay at 50, so we have ^{50}Cr with a mass of 49.946047 u. Under electron capture, Z would decrease by one to Z = 23, while A would still be 50, so we have ^{50}Ti with a mass of 49.944792 u. Finally, if we undergo α-decay, then Z would decrease by 2 to Z = 21 while A would decrease by 4 to A = 46, so we have ^{46}Sc, with a mass of 45.955170 u.

In summary, we have:

β^- decay:	^{50}Cr	m = 49.946047 u
Electron capture:	^{50}Ti	m = 49.944792 u
α-decay:	^{46}Sc	m = 45.955911 u

(b) What is the Q-value for each of these processes? Which of these modes is allowed or excluded?

The Q-values can be computed using the formulas (which you should have memorized). For the first two, it is just the parent minus the daughter masses, while for the third, we must also subtract the ^{4}He mass.

β^- decay:

$$Q = \left(m_P - m_D\right)c^2 = \left(49.947161 - 49.946047\right)\text{u}c^2$$
$$= 0.001114\left(931.494 \text{ MeV}\right) = 1.04 \text{ MeV},$$

Electron capture:

$$Q = \left(m_P - m_D\right)c^2 = \left(49.947161 - 49.944792\right)\text{u}c^2$$
$$= 0.002369\left(931.494 \text{ MeV}\right) = 2.21 \text{ MeV},$$

α-decay:

$$Q = \left(m_P - m_D - m_{4He}\right)c^2$$
$$= \left(49.947161 - 45.955170 - 4.002602\right)\text{u}c^2$$
$$= -0.010611\left(931.494 \text{ MeV}\right) = -9.88 \text{ MeV}.$$

Looking at the final numbers, we would claim that the first two modes are allowed, but the last one is excluded.

38. There is a particle *X* which decays by strong interactions as follows:

$$X \rightarrow \Sigma^- K^- \pi^+$$

All masses in MeV/c^2			
Name	Mass	Spin	Strange
Σ^-	1197	½	-1
K^-	495	0	-1
π^+	135	0	0

The Σ^- is a baryon, and the other two are mesons. The spin and strangeness of the other particles are listed at right. The charges are implied by their names.

(a) What is the charge and strangeness of the *X* particle?

The total charge of the three particles on the right is $(-1)+(-1)+(+1)=-1$, so it must have charge –1. The total strangeness on the right is $(-1)+(-1)+0=-2$, so it must have strangeness –2.

(b) Is it a baryon, anti-baryon, or a meson?

There is one baryon on the right (and no anti-baryons), so there must be one baryon on the left. Hence it is a baryon.

(c) Is it a fermion or a boson?

There must be a total of an even number of fermions in an interaction. The Σ^-, with spin ½, is a fermion, but the other two are bosons, so to make it work out, *X* must be a fermion.

(d) What, if anything, can you conclude about the mass of the *X*?

This is a decay, and therefore the mass of the parent must be greater than the sum of the masses of the products, so we have

$$M_X > M_{\Sigma^-} + M_{K^-} + M_{\pi^+} = 1197\ \text{MeV}/c^2 + 495\ \text{MeV}/c^2 + 135\ \text{MeV}/c^2 = 1827\ \text{MeV}/c^2$$

39. A certain black hole is discovered to have a Schwarzschild radius of 70.0 km.
(a) What is the mass of the black hole?

The Schwarzschild radius is given by $R_S = 2GM/c^2$, so turning this around and solving for *M*, we have

$$M = \frac{c^2 R_S}{2G} = \frac{\left(2.998\times10^8 \text{ m/s}\right)^2\left(7.00\times10^4 \text{ m}\right)}{2\left(6.673\times10^{-11}\text{m}^3/\text{kg}/\text{s}^2\right)} = 4.71\times10^{31} \text{ kg}$$

(b) Hydrogen atoms normally give off radiation with a wavelength of 21.0 cm. If the waves from hydrogen atoms near the black hole produce radiation with a wavelength observed at 28.0 cm, how far is the hydrogen from the black hole?

The gravitational red-shift formula says that

$$\lambda = \lambda_0\left(1-\frac{2GM}{c^2 r}\right)^{-1/2}$$

A bit of algebraic manipulation turns this into

$$1-\frac{2GM}{c^2 r} = \frac{\lambda_0^2}{\lambda^2}$$

Noting that the expression on the left contains the same expression for the Schwarzschild radius, this can be written as

$$1-\frac{R_s}{r} = \left(\frac{\lambda_0}{\lambda}\right)^2 .$$

Rearranging a bit, this becomes

$$\frac{R_s}{r} = 1-\left(\frac{\lambda_0}{\lambda}\right)^2 = 1-\left(\frac{21.0 \text{ cm}}{28.0 \text{ cm}}\right)^2 = 1-\frac{9}{16} = \frac{7}{16}.$$

Cross multiplying, we have

$$16R_S = 7r, \qquad \text{so that} \qquad r = \tfrac{16}{7}R_S = \tfrac{16}{7}\left(70.0 \text{ km}\right) = 160.0 \text{ km}.$$

Equations

Photoelectric effect: $eV_{\max} = hf - \phi$

Basic Masses: $\mathrm{u} = 931.494\ \mathrm{MeV}/c^2 = 1.661\times10^{-27}\,\mathrm{kg}$ $\quad N_A = 6.022\times10^{23}$

Nuclear Decay: $2m_ec^2 = 1.02200\ \mathrm{MeV}$, $\quad M_{\mathrm{He}} = 4.002602\ \mathrm{u}$

Planck's Constants:
$$h = 6.626\times10^{-34}\ \mathrm{J\cdot s} = 4.136\times10^{-15}\ \mathrm{eV\cdot s}$$
$$\hbar = 1.055\times10^{-34}\ \mathrm{J\cdot s} = 6.582\times10^{-16}\ \mathrm{eV\cdot s}$$

Newton's Constant: $G = 6.673\times10^{-11}\mathrm{m}^3/\mathrm{kg}/\mathrm{s}^2$

Gravitational time dilation & Red-shift: $\tau = t\sqrt{1-\frac{2GM}{c^2r}}$

Gravitational Red-shift: $\lambda = \lambda_0\left(1-\frac{2GM}{c^2r}\right)^{-1/2}$ $\quad$ Schwarzschild radius: $R_S = \frac{2GM}{c^2}$

Isotope Masses