Modern Physics & Relativity I

This exam contains mostly Modern Physics and Relativity questions taken from two real GRE exams (one from 1992 and one from 2001). Use this test to develop a strategy for taking the MFAT and GRE exams. For example, under what conditions will you guess an answer as opposed to leaving it blank? How much time will you spend on an individual problem? Use this test to know in what areas of physics you are strong and in what areas of physics you are weak. Study those areas in which you are weak. You can learn the introductory physics you need to succeed on this exam much faster now than you could as a freshman or sophomore.

Remember …
- Your task is NOT to work every problem. It is to find the right answer from a list of five possible ones.
- Be sure to evaluate the five possible answers carefully before attempting to work the problem.
- Techniques such as dimensional analysis and testing limits (maybe you know what the answer should be when $\theta = 90^\circ$, for example) can at least help eliminate wrong choices.
- Statistically, leaving a question blank is equivalent to random guessing.
- If you can eliminate even one choice, there is a statistical advantage to guessing.
- Take note of the kinds of questions and the frequency of questions from the different areas of physics.

This is a timed test. On a real GRE you will have 180 minutes to answer 100 questions. Time yourself on this test.

Allow 43 minutes for the 24 questions.
99. A photon strikes an electron of mass \( m \) that is initially at rest, creating an electron-positron pair. The photon is destroyed and the positron and two electrons move off at equal speeds along the initial direction of the photon. The energy of the photon was

(A) \( mc^2 \)
(B) \( 2mc^2 \)
(C) \( 3mc^2 \)
(D) \( 4mc^2 \)
(E) \( 5mc^2 \)

32. If the total energy of a particle of mass \( m \) is equal to twice its rest energy, then the magnitude of the particle’s relativistic momentum is

(A) \( mc/2 \)
(B) \( mc/\sqrt{2} \)
(C) \( mc \)
(D) \( \sqrt{3} mc \)
(E) \( 2mc \)

33. If a charged pion that decays in \( 10^{-8} \) second in its own rest frame is to travel 30 meters in the laboratory before decaying, the pion’s speed must be nearly

(A) \( 0.43 \times 10^8 \) m/s
(B) \( 2.84 \times 10^8 \) m/s
(C) \( 2.90 \times 10^8 \) m/s
(D) \( 2.98 \times 10^8 \) m/s
(E) \( 3.00 \times 10^8 \) m/s

94. Which of the following is a Lorentz transformation? (Assume a system of units such that the velocity of light is 1.)

(A) \( t' = 4x \)
\( y' = y \)
\( z' = z \)
\( t' = 0.25t \)

(B) \( x' = x - 0.75t \)
\( y' = y \)
\( z' = z \)
\( t' = t \)

(C) \( x' = 1.25x - 0.75t \)
\( y' = y \)
\( z' = z \)
\( t' = 1.25t - 0.75x \)

(D) \( x' = 1.25x - 0.75t \)
\( y' = y \)
\( z' = z \)
\( t' = 0.75t - 1.25x \)

(E) None of the above

34. In an inertial reference frame \( S \), two events occur on the \( x \)-axis separated in time by \( \Delta t \) and in space by \( \Delta x \). In another inertial reference frame \( S' \), moving in the \( x \)-direction relative to \( S \), the two events could occur at the same time under which, if any, of the following conditions?

(A) For any values of \( \Delta x \) and \( \Delta t \)
(B) Only if \( |\Delta x/\Delta t| < c \)
(C) Only if \( |\Delta x/\Delta t| > c \)
(D) Only if \( |\Delta x/\Delta t| = c \)
(E) Under no condition

37. A \( \pi^0 \) meson (rest-mass energy 135 MeV) is moving with velocity \( 0.8c \) \( \hat{k} \) in the laboratory rest frame when it decays into two photons, \( \gamma_1 \) and \( \gamma_2 \). In the \( \pi^0 \) rest frame, \( \gamma_1 \) is emitted forward and \( \gamma_2 \) is emitted backward relative to the \( \pi^0 \) direction of flight. The velocity of \( \gamma_2 \) in the laboratory rest frame is

(A) \(-1.0c \hat{k}\)
(B) \(-0.2c \hat{k}\)
(C) \(+0.8c \hat{k}\)
(D) \(+1.0c \hat{k}\)
(E) \(+1.8c \hat{k}\)

80. A tube of water is traveling at \( 1/2 \) c relative to the lab frame when a beam of light traveling in the same direction as the tube enters it. What is the speed of light in the water relative to the lab frame? (The index of refraction of water is 4/3.)

(A) \(1/2 \) c
(B) \(2/3 \) c
(C) \(5/6 \) c
(D) \(10/11 \) c
(E) \(c\)

85. A free electron (rest mass \( m_e = 0.5 \) MeV/c\(^2 \)) has a total energy of 1.5 MeV. Its momentum \( p \) in units of MeV/c is about

(A) 0.86
(B) 1.0
(C) 1.4
(D) 1.5
(E) 2.0
38. Tau leptons are observed to have an average half-life of $\Delta t_1$ in the frame $S_1$ in which the leptons are at rest. In an inertial frame $S_2$, which is moving at a speed $v_{12}$ relative to $S_1$, the leptons are observed to have an average half-life of $\Delta t_2$. In another inertial reference frame $S_3$, which is moving at a speed $v_{13}$ relative to $S_1$ and $v_{23}$ relative to $S_2$, the leptons have an observed half-life of $\Delta t_3$. Which of the following is a correct relationship among two of the half-lives, $\Delta t_1$, $\Delta t_2$, and $\Delta t_3$?

(A) $\Delta t_2 = \Delta t_1 \sqrt{1 - (v_{12})^2/c^2}$
(B) $\Delta t_1 = \Delta t_2 \sqrt{1 - (v_{13})^2/c^2}$
(C) $\Delta t_2 = \Delta t_1 \sqrt{1 - (v_{23})^2/c^2}$
(D) $\Delta t_3 = \Delta t_2 \sqrt{1 - (v_{23})^2/c^2}$
(E) $\Delta t_1 = \Delta t_2 \sqrt{1 - (v_{23})^2/c^2}$

79. A particle leaving a cyclotron has a total relativistic energy of 10 GeV and a relativistic momentum of 8 GeV/c. What is the rest mass of this particle?

(A) 0.25 GeV/c²
(B) 1.20 GeV/c²
(C) 2.00 GeV/c²
(D) 6.00 GeV/c²
(E) 16.0 GeV/c²

70. A monoenergetic beam consists of unstable particles with total energies 100 times their rest energy. If the particles have rest mass $m$, their momentum is most nearly

(A) $mc$
(B) 10 $mc$
(C) 70 $mc$
(D) 100 $mc$
(E) $10^4 mc$

66. A sample of radioactive nuclei of a certain element can decay only by $\gamma$-emission and $\beta$-emission. If the half-life for $\gamma$-emission is 24 minutes and that for $\beta$-emission is 36 minutes, the half-life for the sample is

(A) 30 minutes
(B) 24 minutes
(C) 20.8 minutes
(D) 14.4 minutes
(E) 6 minutes

68. When $^{7}\text{Be}$ transforms into $^{7}\text{Li}$, it does so by

(A) emitting an alpha particle only
(B) emitting an electron only
(C) emitting a neutron only
(D) emitting a positron only
(E) electron capture by the nucleus with emission of a neutrino

\[
\begin{array}{c|c}
\text{Counts per Minute} & 10^4 \\
\hline
0 & \text{log}_{10} \, 2 = 0.30; \, \text{log}_{10} \, e = 0.43 \\
10 & \\
20 & \\
30 & \\
40 & \\
\end{array}
\]

26. A radioactive nucleus decays, with the activity shown in the graph above. The half-life of the nucleus is

(A) 2 min
(B) 7 min
(C) 11 min
(D) 18 min
(E) 23 min

64. Electromagnetic radiation provides a means to probe aspects of the physical universe. Which of the following statements regarding radiation spectra is NOT correct?

(A) Lines in the infrared, visible, and ultraviolet regions of the spectrum reveal primarily the nuclear structure of the sample.
(B) The wavelengths identified in an absorption spectrum of an element are among those in its emission spectrum.
(C) Absorption spectra can be used to determine which elements are present in distant stars.
(D) Spectral analysis can be used to identify the composition of galactic dust.
(E) Band spectra are due to molecules.
14. An 8-centimeter-diameter by 8-centimeter-long NaI(Tl) detector detects gamma rays of a specific energy from a point source of radioactivity. When the source is placed just next to the detector at the center of the circular face, 50 percent of all emitted gamma rays at that energy are detected. If the detector is moved to 1 meter away, the fraction of detected gamma rays drops to

1. (A) $10^{-4}$
   (B) $2 \times 10^{-4}$
   (C) $4 \times 10^{-4}$
   (D) $8\pi \times 10^{-4}$
   (E) $16\pi \times 10^{-4}$

49. Two horizontal scintillation counters are located near the Earth's surface. One is 3.0 meters directly above the other. Of the following, which is the largest scintillator resolving time that can be used to distinguish downward-going relativistic muons from upward-going relativistic muons using the relative time of the scintillator signals?

   (A) 1 picosecond
   (B) 1 nanosecond
   (C) 1 microsecond
   (D) 1 millisecond
   (E) 1 second

63. The distribution of relative intensity $I(\lambda)$ of blackbody radiation from a solid object versus the wavelength $\lambda$ is shown in the figure above. If the Wien displacement law constant is $2.9 \times 10^{-3} \text{ m.K}$, what is the approximate temperature of the object?

   (A) 10 K
   (B) 50 K
   (C) 250 K
   (D) 1,500 K
   (E) 6,250 K

25. In experiments located deep underground, the two types of cosmic rays that most commonly reach the experimental apparatus are

   (A) alpha particles and neutrons
   (B) protons and electrons
   (C) iron nuclei and carbon nuclei
   (D) muons and neutrinos
   (E) positrons and electrons

14. The total energy of a blackbody radiation source is collected for one minute and used to heat water. The temperature of the water increases from 20.0 °C to 20.5 °C. If the absolute temperature of the blackbody were doubled and the experiment repeated, which of the following statements would be most nearly correct?

   (A) The temperature of the water would increase from 20 °C to a final temperature of 21 °C.
   (B) The temperature of the water would increase from 20 °C to a final temperature of 24 °C.
   (C) The temperature of the water would increase from 20 °C to a final temperature of 28 °C.
   (D) The temperature of the water would increase from 20 °C to a final temperature of 36 °C.
   (E) The water would boil within the one-minute time period.

80. A beam of electrons is accelerated through a potential difference of 25 kilovolts in an x-ray tube. The continuous x-ray spectrum emitted by the target of the tube will have a short wavelength limit of most nearly

   (A) 0.1 Å
   (B) 0.5 Å
   (C) 2 Å
   (D) 25 Å
   (E) 50 Å

16. A student makes 10 one-second measurements of the disintegration of a sample of a long-lived radioactive isotope and obtains the following values.

   3, 0, 2, 1, 2, 4, 0, 1, 2, 5

   How long should the student count to establish the rate to an uncertainty of 1 percent?

   (A) 80 s
   (B) 160 s
   (C) 2,000 s
   (D) 5,000 s
   (E) 6,400 s
95. A beam of $10^{12}$ protons per second is incident on a target containing $10^{20}$ nuclei per square centimeter. At an angle of 10 degrees, there are $10^2$ protons per second elastically scattered into a detector that subtends a solid angle of $10^{-4}$ steradians. What is the differential elastic scattering cross section, in units of square centimeters per steradian?

(A) $10^{-24}$
(B) $10^{-25}$
(C) $10^{-26}$
(D) $10^{-27}$
(E) $10^{-28}$

35. If the absolute temperature of a blackbody is increased by a factor of 3, the energy radiated per second per unit area does which of the following?

(A) Decreases by a factor of 81.
(B) Decreases by a factor of 9.
(C) Increases by a factor of 9.
(D) Increases by a factor of 27.
(E) Increases by a factor of 81.