APP ENTRANCE EXAM - ONLINE QUESTIONNAIRE

24 June 2020

1. **COSMOLOGY**

Consider a spatially flat ($k = 0$) FLRW Universe in which the only energy component is a cosmological constant. How is the scale factor evolving in such a Universe [t_0, a_0 and H_0 being the present time, the scale factor at the present time and the Universe expansion rate at the present time]?

A. $a(t) = a_0 \exp\left[H_0 \left(t - t_0\right)\right]$

B. $a(t) = a_0 \, H_0^{(t-t_0)}$

C. $a(t) = a_0 \left(t - t_0\right)^{2/3}$

D. $a(t) = a_0 \, \exp\left[-H_0 \left(t - t_0\right)\right]$

E. $a(t) = \text{const.}$

2. **COSMOLOGY**

In a FLRW Universe with present-day values of the matter density parameter $\Omega_{\rm m} = 0.1$ and the radiation density parameter $\Omega_{\rm r} = 10^{-4}$, what is the matter radiation equality redshift?

A. $z = 0.001$

B. $z = 99$

C. $z = 101$

D. $z = 999$

E. $z = 1000$

3. **COSMOLOGY**

Consider an empty FLRW Universe with energy density $\rho = 0$. What is the relation between the present time $\rm t_0$ and the Universe expansion rate at the present time $\rm H_0$?

A. $t_0 = \frac{1}{3H_0}$

B. $t_0 = \frac{1}{2H_0}$

C. $t_0 = \frac{2}{3H_0}$

D. $t_0 = \frac{1}{H_0}$

E. $t_0 = \frac{3}{2H_0}$

4. **COSMOLOGY**

In a FLRW cosmological model with curvature parameter $\Omega_K = -0.12$ the comoving distance at redshift $z = 3$ is $d_c = 8$ Gpc. Regarding the angular diameter distance d_D, which of the following relations is true?

A. $d_D < 2$ Gpc
B. $d_D = 2$ Gpc
C. $d_D > 2$ Gpc
D. $d_D = 32$ Gpc
E. $d_D > 32$ Gpc

5. **QFT**

Consider the inelastic scattering of a muon neutrino ν_μ with an electron e^-. Based on symmetry considerations, what is the final state?

A. $\nu_\mu + e^- \to \mu^- + \nu_e$
B. $\nu_\mu + e^- \to \mu^- + \bar{\nu}_e$
C. $\nu_\mu + e^- \to \mu^- + \bar{\nu}_\mu$
D. $\nu_\mu + e^- \to \mu^- + \gamma$
E. $\nu_\mu + e^- \to \mu^- + \nu_\mu$

6. **QFT**

Consider the potential for two real scalar fields ϕ_1, ϕ_2:

$$V(\phi_1, \phi_2) = \frac{m_1^2}{2}\phi_1^2 + \frac{m_2^2}{2}\phi_2^2 + \frac{\lambda_1}{4}\phi_1^4 + \frac{\lambda_2}{4}\phi_2^4 + \frac{\lambda_{12}}{2}\phi_1^2\phi_2^2$$

with $\lambda_1 = 1, \lambda_2 = 2$. Which condition on λ_{12} guarantees the potential is bounded from below?

A. $\lambda_{12} > -2$
B. $\lambda_{12} < \sqrt{2}$
C. $\lambda_{12} > \sqrt{2}$
D. $\lambda_{12} < 2$
E. $\lambda_{12} > 2$

7. **QFT**

Consider the pattern of spontaneous symmetry breaking: $SU(3) \to U(1)$. How many massless degrees of freedom are present in the theory?

A. 1
B. 3
C. 6
D. 7
E. 8

8. **QFT**

Using dimensional analysis, give a parametric estimate of the cross section of the process $e^-\gamma \to e^-\gamma$, in terms of the electron mass m_e and the fine structure constant α. Assume the photon energy is much smaller than the electron mass, and work in natural units $c = 1, \hbar = 1$.

A. α/m_e
B. α/m_e^2
C. α^2/m_e^2
D. α^4/m_e^2
E. α^2/m_e^4

9. **GR**

For a 2-dimensional metric, how many are the independent components of the Riemann tensor?

A. 1
B. 2
C. 3
D. 4
E. 6

10. **GR**

Consider a black hole of mass M. The magnitude of the tidal forces at the horizon is proportional to

A. $1/M^4$
B. $1/M^2$
C. $1/M$
D. M
E. M^2

11. **GR**

A rigid body is axisymmetric and rotates around the axis of symmetry.

A. It does not emit gravitational waves.
B. It emits gravitational waves isotropically.
C. It emits gravitational waves preferentially in the direction of the axis of symmetry.
D. It emits gravitational waves preferentially in the directions orthogonal to the axis of symmetry.
E. It emits gravitational waves along two directions at 45 degrees with the axis of symmetry.

12. **GR**

A circular geodetic orbit in Schwarzschild has angular frequency $\omega = \sqrt{M/r^3}$ (with respect to coordinate time) in units where $G = c = 1$. An observer moving on the innermost stable circular orbit $r = 6M$ performs an experiment on the decay time of strontium 90, measuring $t = t_X$ yr. What is the decay time as measured by an observer at infinity, who is looking at the experimenter with a telescope?

A. $t_X/\sqrt{2}$ yr
B. $t_X \cdot \sqrt{2/3}$ yr
C. t_X yr
D. $t_X/\sqrt{2/3}$ yr
E. $t_X \cdot \sqrt{2}$ yr

13. **GR**

In general relativity one can always choose coordinate where (locally) the Christoffel symbols are zero. Consider now a vacuum curved spacetime and two neighboring geodesics. The change in their proper distance as function of time, predicted by the geodesics deviation equation,

A. is constant because the Christoffel symbols are zero and the spacetime is Ricci flat (because it's vacuum).
B. is not constant because the second derivatives of the metric cannot be set locally to zero.
C. is not constant because even though the Christoffel symbols are zero and the second derivatives of the metric cancel out in the geodesics deviation equation, the third derivatives of the metric do not cancel out.
D. is not constant because even though the Christoffel symbols are zero, the metric is non-degenerate.
E. none of the above.

14. **SPECIAL RELATIVITY**

A passenger is riding a train approaching an alpine tunnel of 100 m rest length, at a speed of a 300 km/h. What is the tunnel length seen by the passenger?

A. 99.999997 m
B. $(100\ -3.8 \times 10^{-9})$ m
C. $(100\ -3.8 \times 10^{-14})$ m
D. $(100\ -3.8 \times 10^{-19})$ m
E. 100.000003 m

15. **SPECIAL RELATIVITY**

Consider the pair annihilation process:

$$X + \bar{X} \to \gamma + Y$$

taking place in the limit of annihilating particles at rest (momenta of particles in the initial state: $|\vec{p}_X| \simeq |\vec{p}_{\bar{X}}| \simeq 0$). What is the approximate energy of the photon γ in the final state, if the mass of X is 500 GeV and the mass of Y is 200 GeV?

A. 300 GeV

B. 440 GeV

C. 460 GeV

D. 480 GeV

E. 500 GeV

16. **THERMAL HISTORY**

In our Universe, as described by the Standard Model for Cosmology and the Standard Model for Particle Physics, the neutrino freeze-out occurs at a temperature of about 1 MeV. Consider another universe characterised by the same properties of our Universe except for Fermi's Coupling Constant G_F being 8 times weaker than in our Universe; at about what temperature would neutrino freeze-out occur in this universe?

A. 0.25 MeV

B. 0.5 MeV

C. 2 MeV

D. 4 MeV

E. 8 MeV

17. **RADIATIVE PROCESSES**

The energy loss rate by synchrotron emission of a relativistic electron of energy $E_e = 1$ GeV in a plasma with given uniform transverse magnetic field $B_\perp$ is about 10^{-10} GeV yr^{-1}. What is the time for an electron of energy $E_e = 10$ GeV to lose half of its energy via synchrotron radiation in a plasma with uniform transverse magnetic field $B_\perp$ 10 times weaker?

A. 10^9 yr

B. 10^{10} yr

C. 10^{11} yr

D. 10^{12} yr

E. 10^{13} yr

18. **QM**

Compute the ratio between the wavelength of a photon of energy $E_\gamma = 1$ eV and the de Broglie wavelength of an electron of mass $m_e \simeq 0.5$ MeV and kinetic energy $K_e = 1$ eV.

A. $2 \cdot 10^{-6}$

B. 10^{-3}

C. 10^{-2}

D. 1

E. $5 \cdot 10^5$

19. **QM**

A free atom of carbon has 2 electrons in p-wave orbital wave functions ($L = 1$). How many states are permitted for this pair of electrons?

A. 2

B. 4

C. 6

D. 15

E. 30

20. **QM**

The fine structure of atomic spectral lines arises from

A. nuclear spin

B. interaction between electron and nucleus

C. electron spin-spin coupling

D. electron spin-orbit coupling

E. none of the above