Q5 The key contains statements about the *curvature of four-dimensional spacetime*. Select the item that is a *true* statement. Pencil across *one* cell in row 5.

KEY for Q5

A If a region of spacetime contains no matter, the Riemann curvature within that region must be zero.

B The source terms in the field equations uniquely determine the metric coefficients of spacetime.

C The Reimann curvature at a given event can be zero while the Ricci curvature at the same event is non-zero.

D The Ricci curvature at a given event in spacetime depends only on the source terms at that event.

E None of statements A–D is true.

Q6 to Q10 are concerned with the geometric properties of two-dimensional surfaces.

Q6 to Q8 These questions refer to a two-dimensional surface S that is described by the metric

$$\Delta l = \left[\left(\Delta q^1\right)^2 + \cos^2\left(\lambda q^1\right)\left(\Delta q^2\right)^2 \right]^{1/2}$$

where λ is a positive constant.

Q6 What is the curvature of the surface S at the point $q^1 = 0$, $q^2 = 0$? Pencil across *one* cell in row 6.

KEY for Q6

A 0

B $-\lambda/2$

C $\lambda/2$

D $-\lambda^2/2$

E $\lambda^2/2$

F $-\lambda^2$

G λ^2

Q7 A small but *finite* circle centred on the point $q^1 = 0, q^2 = 0$ is drawn on the surface S with the aid of a measuring tape. Which of the statements in the key would best describe the relationship between C, the circumference of the circle, and r, the radius of the circle? Pencil across *one* cell in row 7.

KEY for Q7

A C is greater than $2\pi r$.

B C is equal to $2\pi r$.

C C is less than $2\pi r$.

D The metric does not give sufficient information to choose between options A, B and C.

Q8 A small but *finite* triangle (whose sides are geodesics) is drawn on the surface S with one vertex at $q^1 = 0, q^2 = 0$. Which item from the key describes the sum of the interior angles of the triangle? Pencil across *one* cell in row 8.

KEY for Q8

A The sum exceeds π.

B The sum is less than π.

C The sum equals π.

D None of the above options must apply.

Q9 On a different surface S′ (not the surface of Q6 to Q8), circles are constructed. It is found that the ratio of circumference to radius of these circles is greater than 2π, *regardless* of where on the surface the centres lie. Which if any, of the surfaces A–F in the key might produce this result? Pencil across *one* cell in row 9.

KEY for Q9

A A right circular cylinder

B A sphere viewed from the outside

C A sphere viewed from the inside

D An ellipsoid of revolution

E A paraboloid of revolution

F A torus

G None of A–F

Q10 The metric of a surface, in the coordinate system (x^1, x^2) is given by

$$\Delta l = \left[\left(\Delta x^1\right)^2 + \left(x^1\right)^2 \left(\Delta x^2\right)^2 \right]^{1/2}.$$

Two curves are drawn on this surface. Curve C_1 has the parametrization $x^1 = a$ and $x^2 = bs + c$. Curve C_2 has the parametrization $x^1 = as + b$ and $x^2 = c$. For both curves a, b and c are arbitrary constants, which may be non-zero, and s is the parameter. Pick from the key, which is given as a table, the one option that correctly describes whether the surface is flat or curved, and whether curves C_1 and C_2 are geodesics or not. Pencil across *one* cell in row 10.

KEY for Q10

option	flat	curved	C_1 geodesic	C_2 geodesic
A	yes	no	yes	yes
B	no	yes	yes	yes
C	yes	no	yes	no
D	no	yes	yes	no
E	yes	no	no	yes
F	no	yes	no	yes
G	yes	no	no	no
H	no	yes	no	no

Q11 to Q13 are concerned with Schwarzschild spacetime.

Q11 to Q13 share the same key. Each question consists of two statements (a) and (b). You are to decide first whether each statement is true or false. Second, if you decide that both statements are true, you are to decide whether or not the truth of statement (b) is a significant part of the reason (possibly the whole reason) for the truth of statement (a). Each answer will thus consist of two or three items from the key. The questions refer to two events, ε_1 and ε_2, with coordinates $(t_1, r_1, \theta_1, \phi_1)$ and $(t_1 + \Delta t, r_1 + \Delta r, \theta_1, \phi_1)$, respectively, where $r_1 \gg \Delta r > 0$ and $\Delta t > 0$.

Q11 *Statement (a)* If the two events occurred at the ends of a rigid rod, then the length of that rod is equal to Δr, no matter what the value of Δt might be.

$l = (R^2(\Delta\theta)^2 + R^2\sin^2\theta(\Delta\phi)^2)^{1/2}$

$= R((\Delta\theta)^2 + \sin^2\theta(\Delta\phi)^2)^{1/2}$