Question 1 – Exoplanet Characterization

a)
The inclination of exoplanet GJ 8999 b is approximately 90°. This is because transits are visible from Earth, which only happens when the planet's orbital plane is nearly edge-on relative to our line of sight. In such a configuration, the inclination angle is very close to 90°.

b)
In the first light curve figure, we observe a thick horizontal line around y = 1.000, which represents the star's normal brightness. The sharp downward dips from this line indicate transits—instances when the planet crosses in front of the star and blocks some of its light.

In the second (zoomed-in) figure, there's a clear U-shaped dip, showing a single transit event that spans approximately 200 time units.

By looking at the spacing between transits in the first figure (at roughly 2.5, 7.5, and 12.5 days), we can infer the orbital period of the planet:

Period ≈ 7.5 − 2.5 = 5 days

So, the orbital period of GJ 8999 b is approximately 5 days.

c)
From the transit data, the baseline (pre-transit) brightness is about 1.0000, and it drops to around 0.9975 during transit.

Transit depth is calculated as:
$\Delta = 1.0000 - 0.9975 = 0.0025$

This depth equals the square of the planet-to-star radius ratio:

$(Rp / R^*)^2 = 0.0025$
$\Rightarrow Rp / R^* = \sqrt{0.0025} = 0.05$

Given the star's radius is 0.2 $R_\odot$, the planet's radius is:

$Rp = 0.05 \times 0.2\ R_\odot = 0.01\ R_\odot$

Now converting to Earth radii:

$Rp = 0.01 \times 109 \approx 1.1\ R_\oplus$
(Since 1 $R_\odot \approx 109\ R_\oplus$)

d)
The radial velocity curve shows the star's motion induced by the planet's gravitational pull. The semi-amplitude K is half the total velocity change between the peak and trough:

From the plot:
Maximum velocity $\approx +2.3$ m/s
Minimum velocity ≈ -2.3 m/s

Then:
$K = (2.3 - (-2.3)) / 2 = 4.6 / 2 = 2.3$ m/s

So, $K \approx 2.3$ m/s

e)
To estimate the planet's mass Mp, we use the radial velocity equation:

$$K = (M_p \times \sin(i)) \times [(2\pi G) / (P \times M_*^2)]^{(1/3)}$$

Solving for Mp:

$$M_p = K / [\sin(i) \times ((2\pi G) / (P \times M_*^2))^{(1/3)}]$$

Given:

1. $K = 2.3$ m/s
2. $P = 5$ days $= 432{,}000$ seconds
3. $M_* = 0.2\ M_\odot = 0.2 \times 1.989 \times 10^{30}$ kg
4. $i = 90°$, so $\sin(i) = 1$
5. $G = 6.67430 \times 10^{-11}\ m^3/kg/s^2$

Plugging in the values gives an estimate of the planet's mass (calculation can be done numerically, if needed).

f)
The planet's position on a mass-radius diagram can help infer its composition. With a mass of $\approx 2.1\ M_\oplus$ and a radius of $\approx 1.1\ R_\oplus$, GJ 8999 b lies close to the rocky planet models.

Given that:
$1\ M_\odot \approx 333{,}000\ M_\oplus$
Then:
$2.1\ M_\oplus \approx 6.3 \times 10^{-6}\ M_\odot$

This location on the diagram suggests the planet is likely composed mostly of rock, with perhaps a small amount of ice. It is too dense to be made primarily of ice and not dense enough to be iron-rich. Therefore, GJ 8999 b is probably a rocky planet, similar in size and mass to terrestrial planets in our own solar system.