Answer THREE questions
The numbers in square brackets indicate the provisional allocation of maximum marks per sub-section of a question.

Stefan-Boltzmann constant	s =	5.67×10^{-8}	J m^{-2} K^{-4} s^{-1}
Mean Sun-Earth distance	AU=	1.5×10^{11}	m
Mean Sun-Venus distance		0.72	AU
Mean Sun-Mars distance		1.52	AU
Solar constant at 1AU		1370	Wm^{-2}

1. The equation of motion for air in an atmosphere may be written:

$$\frac{v^2}{R} = -2\Omega v \sin f - \frac{1}{r}\frac{\partial P}{\partial n}$$

where the coordinate n is directed normal to the flow and positive to the left, v is the flow velocity, r the atmospheric density, P the pressure, Ω the angular velocity of planetary rotation, f the latitude and R the radius of curvature of the wind motion in the atmosphere. The radius of curvature is measured towards the centre of rotation and is positive when parallel to n.

State and explain the two principal approximations to this equation and the main assumptions needed to produce them. For each of the approximations, sketch and describe the circulation of air in the Northern hemisphere and how it relates to low or high pressures at its centre. How would these differ in the Southern hemisphere?

[12]

What is the Rossby number and how is it used to determine which approximation is valid? Calculate its value for the following cases and comment on the nature of each system.

	Planetary rotation period (h)	Wind speed (m s^{-1})	Size (km)	Latitude
Low pressure	24h	12	1000	50
Cyclone	24h	48	100	20
Tornado	24h	100	0.1	30
Great red spot (Jupiter)	9.8h	100	15000	20

[8]

2. What is meant by the term exobase? Show that, in an isothermal atmosphere, the mean free path at the exobase is equal to the scale height. **[10]**

Briefly describe the various processes by which particles may be lost from an atmosphere. Why is gas from the exosphere removed directly by the solar wind at Mars and Venus but not Earth? What do you consider could be the most important exospheric loss process at

Pluto?

[10]

3. Name the four main regions of Jupiter's atmosphere and sketch the vertical structure in that atmosphere as a graph of pressure against temperature.

[6]

Describe briefly the main heating and cooling mechanisms at work in each layer.

[8]

Explain the terms equilibrium and effective temperature when there is an internal heat source. Given that Jupiter's equilibrium temperature is 56 K, its effective temperature is 46 K, and its albedo is 0.29, calculate the magnitude of the internal heat source in units of the solar heat input.

[6]

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4. Why is the presence of ozone important for life on Earth? What is meant by the term 'ozone hole'? What is the main ozone destruction mechanism and what are the chemical reactions involved? **[6]**

Describe why significant depletion of ozone only occurs over one of Earth's poles at a particular time of year. **[10]**

Why is ozone present in the stratosphere of Earth but not at Mars or Venus?

[4]

5. Sketch the spectrum of radiation from the Sun incident on the Earth and of the radiation emitted from the Earth. Using the sketch, discuss the difference between the two and how the properties of the atmosphere leads to a greenhouse effect. Discuss how an increase in the optical depth affects the greenhouse effect using the equation

$$B_g = \frac{f}{2p}\left(c_0^{\ *} + 2\right)$$

Where B_g is the black body radiation from the ground, ϕ is the net radiation flux and χ_0^* is the optical depth measured from the top of the atmosphere.

[6]

By equating the incident and emitted radiation flux, show that the equilibrium temperature of a body in space which reflects no light is approximately

$$T = 279R^{-1/2}$$

Kelvin, where *R* is the distance from the body to the Sun in AU.

Use this expression to calculate the equilibrium temperatures of Venus, Earth and Mars.

[6]

 END OF PAPER

Using your calculated values as a starting point, sketch the relationship between temperature and water vapour pressure at the three planets. Use the sketch to discuss the greenhouse effect due to water at the three planets. **[8]**