On admission to the examination room, you should acquaint yourself with the instructions below. You <u>must</u> listen carefully to all instructions given by the invigilators. You may read the question paper, but must <u>not</u> write anything until the invigilator informs you that you may start the examination.

You will be given five minutes at the end of the examination to complete the front of any answer books used.

DO NOT REMOVE THIS QUESTION PAPER FROM THE EXAM ROOM.

April 2015 **MTMG21 2014/15 A001**

Answer Book
Data Sheet
Any bilingual English language dictionary permitted
Any non-programmable calculator is permitted

UNIVERSITY OF READING

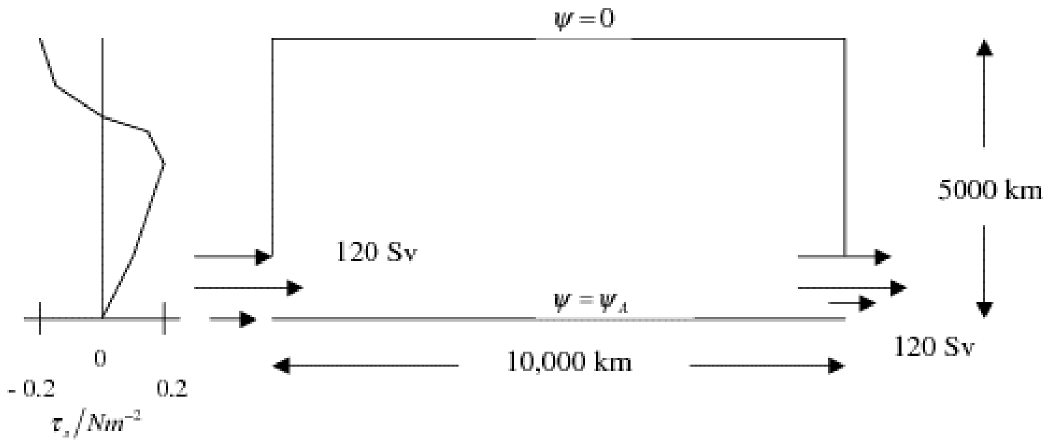
OCEANOGRAPHY (MTMG21)

Two hours

Answer **ANY TWO** questions

The marks for the individual components of each question are given in [ ] brackets. The total mark for the paper is 100

1. The figure below shows an idealised model of the Southern Ocean, consisting of a single closed basin to the north and a circumpolar channel to the south. The ocean is assumed homogeneous, constant depth *H*=4 km, and is forced by a zonal wind stress which varies with latitude as shown. A prescribed current of 120 Sv flows through the model Drake passage.



(a) Assuming that the interior circulation is depth-independent and described by Sverdrup balance, write down an expression for the meridional velocity v (which is the same as its vertically-averaged value).

[10 marks]

(b) Defining a stream-function ψ for the fluid velocity (u,v), write down a differential relation relating ψ to the wind stress $\boldsymbol{\tau}_S$, and discuss the appropriate boundary conditions. Thus show that

$$\psi(x,y) = \psi(L,y) + \frac{1}{\beta\rho_0 H}\frac{\partial\tau_s}{\partial y}(L-x) \qquad \text{(Eq. 1)}$$

where the eastern boundary is located at x=L.

[10 marks]

(c) If ψ=0 along the northern boundary of the basin, deduce the value of $\psi=\psi_A$ along the southern (Antarctic) coastline.

[10 marks]

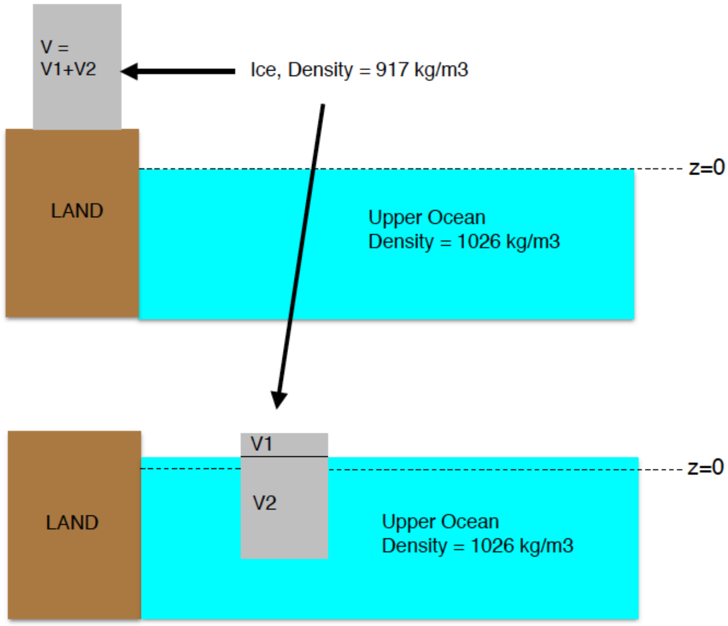
(d) Sketch the form of the streamline predicted by Sverdrup balance, indicating the location and direction of any boundary currents required to close the circulation.

[10 marks]

(e) Estimate the transport of the subtropical gyre giving your answer in Sverdrups.

[10 marks]

2. Sea level change due to ice sheet discharge and floating ice melting



(a) An ice sheet of volume V initially on land (top panel of figure 2) is dumped into the ocean (bottom panel), thus raising sea level. Because sea ice is less dense (ρ_{ice} = 917 kg/m^3) than seawater (ρ_0=1026 kg/m^3), some volume V1 of the floating sea ice will be above the sea surface, with the remaining volume V2=V-V1 being below the sea surface.

By what volume does the sea level increase as the result of the dumping of the ice sheet into the ocean? Is it V1, V2 or V? Justify your answer.

[5 marks]

(b) Use Archimedes principle to show that the fraction of volume V2 below the sea level is given by

$$V_2 = \frac{\rho_{ice}}{\rho_0} V$$

[10 marks]

(c) Assume that the ice sheet can be modelled as a cylinder of height h=500 m and area A=1000 km^2. Use your answer to (b) to compute the height of floating ice above the sea level, and your answer to (a) to compute the increase in sea level, assuming that the total area of the ocean is 3.10^{14} m^2.

[10 marks]

(d) The floating sea ice is now melted into pure freshwater of density ρ_{fresh} = 1000 kg/m^3.
(i) What is the volume of the melted water V_{melt}, given the data given in (c)?
(ii) What is the sea level increase resulting from adding V_{melt} of freshwater to the initially undisturbed ocean?
(iii) Conclude as to whether the melting of floating sea ice adds a further contribution to sea level increase as compared to your answer to question (c), and if yes, what is the additional sea level increase as compared to just dumping the ice sheet into the ocean?

[15 marks]

(e) Why do we expect sea level to increase as the result of global warming? What would be the expected increase in sea level due to 1degree Celsius mean increase of the ocean, assuming the thermal expansion coefficient to be $\alpha=10^{-4}$ K^{-1}?

[10 marks]

3. General knowledge about the ocean circulation

(a) Explain what coastal upwelling is, and why it is important for the fishing industry. Your explanation should include a discussion of the relevant physical processes, and indicate where the major upwelling regions in the oceans are located. How are these upwelling regions affected by El Nino?

[10 marks]

(b) Explain the physical principles underlying the measurement of sea surface height using satellite altimeters. Your explanation should include a discussion of the geoid, and of the typical corrections typically done to isolate the sea surface height signal related to the large-scale ocean dynamics and eddies.

[10 marks]

(c) Explain why the properties of the water masses in the ocean interior tend to reflect winter surface conditions. Do you think that the annual mean state of the ocean can be correctly simulated by using annually-averaged surface fluxes in ocean modelling? Justify your answer.

[10 marks]

(d) Imagine that you are given the task of monitoring the heat and mass transport across the Drake Passage. Explain how you would go about it, and what kind of instruments and measurement techniques you would use to accomplish this.

[10 marks]

(e) Discuss the physical principles important for understanding the thermohaline circulation of the ocean, and explain the relative importance of the wind and the buoyancy forcing in driving it.

[10 marks]

(End of Question Paper)