Useful physical and mathematical constants:

\[ R = 8314 \text{ } J/\text{mole} \cdot \text{K} \; ; \; \sigma = 5.735 \times 10^{-8} \text{ } \text{Wm}^{-2} \text{K}^{-4} \; ; \; \pi = 3.14159 \; \text{g} = 6.674 \times 10^{-11} \text{m}^3 \text{kg}^{-1} \text{s}^{-2} \]

Earth parameters:

\[ R_E = 6371 \text{ } \text{km} \; ; \; a_E = 0.33 \; ; \; g = 9.81 \text{m/s}^{2} \; ; \; \gamma = -g/c_p = -9.8^\circ\text{C/km} \; , \; \text{Tilt} = 23.5^\circ \]

\[ H_s = R_s T/\text{g} = 8.4 \text{km} \; ; \; S = 1380 \text{W/m}^2 \; ; \; \Omega = 7.27 \times 10^{-5} \text{ } \text{s}^{-1} \; ; \; M = 5.974 \times 10^{24} \text{kg} \]

Properties of air:

\[ R_{\text{air}} = 287 \text{ } J/\text{kg} \cdot \text{C} \; ; \; \rho_{\text{air}} = 1.2 \text{ } \text{kg/m}^3 \; , \; C_{P_{\text{air}}} = 1004 \text{ } J/\text{kg} \cdot ^\circ \text{C} \]

Properties of water:

\[ \rho_{\text{water}} = 10000 \text{ } \text{kg/m}^3 \; ; \; \rho_{\text{ice}} = 917 \text{ } \text{kg/m}^3 \; ; \; \rho_{\text{SEA}} = 1025 \text{ } \text{kg/m}^3 \]

\[ L_{\text{COND}} = 2.5 \times 10^6 \text{ } J/\text{kg} \; ; \; L_{\text{FREEZE}} = 3.34 \times 10^5 \text{ } J/\text{kg} \]

\[ C_{P_{\text{water}}} = 4218 \text{ } J/\text{kg} \cdot ^\circ \text{C} \]

Useful definitions:

\[ RH = \frac{P}{P_{\text{sat}}} \; ; \; \text{ResTime} = \frac{C}{F} \; ; \; \delta D = [(\frac{P}{\text{REF}})/(\frac{P}{\text{REF}})] - 1] \times 1000 \]

Useful physical laws and balances:

\[ gM = PA \; ; \; F_G = \frac{GMm}{r^2} \; ; \; \rho = \rho RT \; ; \; \Delta \rho = -\rho g \Delta Z \; ; \; \text{Rgas} = \text{Runiversal}/M \]

\[ V_c = \sqrt{2gR_E} \; ; \; V_m = \sqrt{\frac{3RT}{M}} \; ; \; Q = MC_p\Delta T \; ; \; Q = L\Delta m_c \]

\[ R = \sqrt{K \cdot T} \; ; \; R_{\text{plane}} = \sqrt{K_x/U} \]

\[ CF = 2MU_0^2\sin\phi \; ; \; \tau = 0.003\rho_A U_A^2 \; ; \; F = \sigma T^4 \; ; \; \lambda_m T = 2898 \text{microns} \cdot ^\circ \text{K} \]

\[ PET(\text{mm/month}) = 5 \times T(C) \; ; \; P = P_0 e^{-\Delta H} \; ; \; \rho = \rho_0 e^{-Z/H_S} \]

\[ T = \sqrt{\frac{S(1-a)}{4\sigma}} \; ; \; T_{ch} = T/(1 - \frac{\Omega}{2})^{1/4} \]

\[ A_S = 4\pi R^2 \; ; \; V = (4/3)\pi R^3 \; ; \; F = S\cos(\phi) \]
\[ U_{\text{Water Flux}} = \rho_w U A \]

\[ U_{\text{Salt Flux}} = S \rho_w U A \]

\[ U_{\text{Heat Flux}} = C_p T \rho_w U A \]

\((\Delta p / L) \ Vol = \rho \times 2 \times \Omega \times \sin \phi \times U \times Vol\)

\[ PE = M g z \]

\[ EFF = \Delta T / T \]

\[ Q_{\text{out}} = K \sqrt{\text{Zeppf}} \]

\[ P(t) = P(t = 0) \exp(\gamma t) \]

\[ P_{\text{Wind}} = \left(\frac{1}{2}\right) \varepsilon \rho U^3 A \]

\[ P_{\text{Solar}} = \varepsilon \sigma T A \cos(\phi) \]

\[ P_{\text{HYDRO}} = \varepsilon \rho_w g z A \]

**Unit Conversions:**

\[ \text{ppmv} = \frac{M_{\text{AIR}}}{M} \text{ ppmv}; \quad 1 \text{ mb} = 100 \text{ Pascals}; \quad 0^\circ C = 273.1 \text{ K} \]

\[ 1 \text{ knot} = 0.54 \text{ m/s}; \quad 1 \text{ inch} = 2.54 \text{ cm}; \quad ^\circ C = \frac{5}{9}(^\circ F - 32) \quad 1 \text{ tonne} = 10^3 \text{ kg} \]

<table>
<thead>
<tr>
<th>T (°C)</th>
<th>P_{\text{sat}} (mb)</th>
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</thead>
<tbody>
<tr>
<td>-10</td>
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<tr>
<td>0</td>
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<td>10</td>
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<tr>
<th>Molecular Weights</th>
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<tr>
<td>H₂</td>
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<td>N₂</td>
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<td>O₂</td>
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<tr>
<td>CO₂</td>
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<tr>
<td>Air</td>
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</tbody>
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1. [10] A top view of a Foucault Pendulum base plate is shown with the track of the bob as it swings across. Sketch forces on the bob and explain how the track will rotate if the pendulum is in the southern hemisphere.

![Foucault Pendulum](image)

2. [10] Explain how cool winds and a gustfront are created by a thunderstorm.
3. [10] If at 45 degrees north latitude, the horizontal pressure gradient is 0.002 Pa/m with pressure increasing towards the west:
   a. **Estimate** wind speed above the turbulent boundary layer.
   b. **Give** the wind direction. (include a **sketch** showing forces)
   c. **Explain** the force balance you have assumed to do this problem.

4. [10] Explain why the clear sky appears blue but a cloud appears white under similar illumination from the sun.

5. [10] Why are hurricanes not found over the sea
   a. Near the equator
   b. In the tropical south Atlantic

6. [10] Explain why water drops may form on the outside of a cool glass of water. What condition is required?
7. [10] Describe how the raindrops form that fall from a tall cumulo-nimbus cloud.

8. [10] If a mid-latitude cyclone in the northern hemisphere transports \(10^{11}\, kg/s\) of air northward with \(T=20C\) and an equal mass of air moves southward with \(T=10C\), how much heat is transported northward? Express your answer in Watts. What happens to this heat transported northward?

9. [10] On a rainy day, a centimeter of rain falls on a 10000 square kilometer area (i.e. 100 by 100km). Estimate the latent heat released to the atmosphere in the clouds causing that precipitation. Express your answer in Joules.

10. [10] Explain the reason for the rainy season at each location below.

   a. Jerusalem, Israel/Jordan/Palestine (Lat =32N, Long = 35E) The wettest month is January (P = 5.1 inches; temperature of \(T = 44F\)). The driest month is July (P=0; T=73F).

   b. Asuncion, Paraguay (25S, 58W) The wettest month is December (P=6.2 inches, T=80F). The driest month is July (P=2.2 inches, T=64F)