Midterm Exam III
November 25, 2:10 – 3:25 pm, HW714

- Chapters 7 (7.12 – 7.17), 8 and 9 (through section 9.15, included)
- 60 multiple choice questions
- This exam constitutes 22% (only) of your total (overall) grade

Remember to bring pencils!! (No. 2) and to follow the instructions about writing your names on both exam and answer sheets, as well as to 'bubble' your names (no IDs!) on the appropriate place of the answer sheet (on the back).

Guide to study: answer the questions from the Concept Check (CC) boxes in textbook:

- Chapter 7: 13, 14, 15, 16, 17, 18, 19 and 20.
- Chapter 8: 1 through 14, 16 through 21, 26 through 30.
- Chapter 9: 1, 3 through 17.

Chapter 7 - second half
Ocean Chemistry

Keep in mind:
Ocean salinities vary in space
Processes that affect salinity: evaporation, precipitation, runoff, freezing, and thawing
And recall that:
The heat capacity of water decreases with increasing salinity
As salinity increases, freezing point decreases
As salinity increases, evaporation slows (boiling point increases)

Recall: Seawater's constituents may be conservative or nonconservative

- Conservative: concentration changes only as a result of mixing, diffusion, and advection
- Non-conservative: concentration changes as a result of biological or chemical processes as well as mixing, diffusion, and advection

Q: Are dissolved nitrogen, oxygen and carbon dioxide conservative or non-conservative constituents of seawater?

Make sure to answer questions 13 - 16 on page 195 and questions 17 - 20 on page 197. In addition make sure you can explain figure 7.12 of the textbook (page 198)
Distribution with depth
- Photosynthesis removes CO₂ and produces O₂ at the surface
- Respiration produces CO₂ and removes O₂ at all depths
- Compensation depth (Photosynthesis = Respiration)

### Table 4.1: Abundance of Gases in Air and Seawater

<table>
<thead>
<tr>
<th>Gas</th>
<th>Symbol</th>
<th>Percentage by Volume in Atmosphere</th>
<th>Percentage by Volume in Surface Seawater</th>
<th>Percentage by Volume in Total Oceans</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>78.19</td>
<td>46</td>
<td>0</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>20.99</td>
<td>36</td>
<td>6</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>0.04</td>
<td>1.8</td>
<td>100</td>
</tr>
<tr>
<td>Allelu, kelp, etc.</td>
<td>Ar, He, Ne</td>
<td>0.01</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100.06</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

1. Henry = 800, temperature = 20°C

Oxygen and CO₂ profiles

- **O₂ Concentrations**
  - Photosynthesis
  - Bottom water enrichment

- **CO₂ Concentrations**
  - Direct solution of gas from the atmosphere
  - Respiration of marine organisms
  - Oxidation (decomposition) of organic matter

### The Carbon/Carbon Dioxide Cycle
- Ocean uptake from atmosphere
  - Depends on: pH, temperature, salinity, chemistry
- Biological pump

| Numbers in black = rates of exchange | Numbers in green = total amounts stored in reservoirs | Numbers in parenthesis = net annual changes |

Some words to keep in mind:
- Ion - charged atom
  - cat-ion (+) - positively charged ion
  - an-ion (-) - negatively charged ion

Dissociation = to break apart into ions

\[
\text{H}_2\text{O} \rightarrow \text{OH}^- + \text{H}^+ 
\]

Pure Water:

\[
[\text{H}^+] = 10^{-7} \\
[\text{OH}^-] = 10^{-7} 
\]

Neutral solution: \([\text{H}^+] = [\text{OH}^-]\)

(all 3 will be in water solutions)
Non-pure water solutions

- $[\text{OH}^-]$ and $[\text{H}^+]$ are inversely proportional
- Imbalance between the relative concentration of $\text{H}^+$ and $\text{OH}^-$ produces an acidic or basic solution
- pH scale - measures acidity/alkalinity
  - 0-14
  - Logarithmic scale: $\text{pH} = -\log_{10}[10^{-5}] = 5$
  - pH of rainwater ~ 5-6 (on the acidic side)

Seawater

- Alkaline, pH from 7.5-8.5
- Average pH=8.0
- pH relatively constant due to buffering action of CO$_2$
- Buffer = substance that prevents sudden or large changes in the acidity or alkalinity of a solution
- Important for biological processes
- pH inversely proportional to the concentration of CO$_2$

CO$_2$ Buffer

CO$_2$ combines readily with seawater to form carbonic acid (H$_2$CO$_3$). Carbonic acid can then lose a H$^+$ ion to become a bicarbonate ion (HCO$_3^-$), or two H$^+$ ions to become a carbonate ion (CO$_3^{2-}$). Some bicarbonate ions dissociate to form carbonate ions, which combine with calcium ions in seawater to form calcium carbonate (CaCO$_3$), used by some organisms to form hard shells and skeletons. When their builders die, these structures may fall to the seabed as carbonate sediments, eventually to be redissolved. As the double arrows indicate, all these reactions may move in either direction.
**CO₂ Buffer**

\[ \text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3 \rightarrow \text{HCO}_3^- + \text{H}^+ \text{ or } \text{CO}_3^{2-} + 2\text{H}^+ \]

- \text{carbonic acid}
- \text{bicarbonate}
- \text{carbonate}

\text{CO}_2 \text{ Concentrations depend on:}
- Direct solution of gas from the atmosphere
- Respiration of marine organisms
- Oxidation (decomposition) of organic matter

\text{No need to remember chemical equation!}

**Chapter 7 - Summary**

Most solids and gases are soluble in water.

The ocean is in chemical equilibrium, and neither the proportion nor the amount of most dissolved substances changes significantly through time.

Nitrogen is the most abundant dissolved gas in seawater; oxygen is the second most abundant.

Carbon dioxide is the most soluble gas, and one of many substances that affect the ocean’s pH balance.

Seawater acts as a buffer to prevent broad swings of pH when acids or bases are introduced.

pH: acidity of seawater 7.5 - 8.5

Carbon dioxide acts as a buffer that prevents large variations in pH

Biological processes pump CO₂ into the deep ocean

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**Chapter 8
Circulation of the Atmosphere**

Please refer to the available power point (or pdf format) lecture on this chapter. Use the entire lecture as a guide for studying, as all concepts were covered and discussed in class, so I do not need to repeat this presentation here.

Make sure you review the answers to all questions in the "Concept Check" boxes of the chapter (see first page of this review) and that you review the sections that were assigned for you to read. The larger portion of this exam is on the material of this chapter.

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**Chapter 9
Circulation of the Ocean**

What is geostrophic flow?

Review the basic mechanisms operating in the first 20-300 meters of the ocean that result in the Ekman ‘spiral’ and Ekman transport (forces, angles between wind and surface current, deflection of layers below the surface)

Be able to name and locate the major surface currents in the ocean.
Surface Currents Are Driven by the Winds

The westerlies and the trade winds are two of the winds that drive the ocean’s surface currents.

About 10% of the water in the world ocean is involved in surface currents, water flowing horizontally in the uppermost 400 meters (1,300 feet) of the ocean’s surface, driven mainly by wind friction.

(left) Winds, driven by uneven solar heating and Earth’s spin, drive the movement of the ocean’s surface currents. The prime movers are the powerful westerlies and the persistent trade winds (easterlies).

Surface Currents

What are some effects of ocean currents?

- Transfer heat from tropical to polar regions
- Influence weather and climate
- Distribute nutrients and scatter organisms

Surface currents are driven by wind:

Most of Earth’s surface wind energy is concentrated in the easterlies and westerlies. Due to the forces of gravity, the Coriolis effect, solar energy, and solar winds, water often moves in a circular pattern called a gyre.

Surface Currents Are Driven by the Winds

A combination of four forces - surface winds, the sun’s heat, the Coriolis effect, and gravity - circulates the ocean surface clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, forming gyres.

The North Atlantic gyre, a series of four interconnecting currents with different flow characteristics and temperatures.

Surface Currents Flow around the Periphery of Ocean Basins

Surface water blown by the winds at point A will veer to the right of its initial path and continue to the east.

Water at point B veers right and continues to the west.
The Ekman 'spiral' and how it works.

The effect of Ekman spiraling and the Coriolis effect cause the water within a gyre to move in a circular pattern.

The movement of water away from point B is influenced by the rightward tendency of the Coriolis effect and the gravity-powered movement of water down the pressure gradient.

Review and keep in mind:

Coriolis at work!
At the surface:

\[
\text{Direction of wind-driven surface water in Northern Hemisphere}
\]

Ekman Spiral & Ekman Transport

All angles are measured with respect to the wind direction:
- black – wind
- blue – current
- purple – Ekman transport
Review!
The Ekman ‘spiral’ and Ekman transport

- Coriolis effect
- Frictional coupling between water layers is small
- Each successive layer experiences greater deflection
- ‘Spiral’ extends to 100 - 150 m depth
- Surface Water will move 45° with respect to the wind
- Net movement of water when integrated (summed) through the water column (Ekman spiral) will be 90° with respect to the wind

Surface Currents Flow around the Periphery of Ocean Basins

The surface is raised through wind motion and Ekman transport to form a low hill. The westward-moving water at B ‘feels’ a balanced pull from two forces: the one due to Coriolis effect (which would turn the water to the right) and the one due to the pressure gradient, driven by gravity (which would turn it to the left).

The hill is formed by Ekman transport. Water turns clockwise (inward) to form the dome, then descends, depressing the thermocline.

Seawater Flows in Six Great Surface Circuits

Geostrophic gyres are gyres in balance between the pressure gradient and the Coriolis effect. Of the six great currents in the world’s ocean, five are geostrophic gyres. Note the western boundary currents in this map.

Boundary Currents Have Different Characteristics

**Western boundary currents** - These are narrow, deep, fast currents found at the western boundaries of ocean basins.
- The Gulf Stream
- The Japan Current
- The Brazil Current
- The Agulhas Current
- The Eastern Australian Current

**Eastern boundary currents** - These currents are cold, shallow and broad, and their boundaries are not well defined.
- The Canary Current
- The Benguela Current
- The California Current
- The West Australian Current
- The Peru Current
Surface Currents Affect Weather and Climate

Wind induced vertical circulation is vertical movement induced by wind-driven horizontal movement of water.

Upwelling is the upward motion of water. This motion brings cold, nutrient rich water towards the surface.

Downwelling is downward motion of water. It supplies the deeper ocean with dissolved gases.

Review how wind can induce upwelling and downwelling & the concepts of convergence and divergence.

El Niño and La Niña Are Exceptions to Normal Wind and Current Flow

In an El Niño year, when the Southern Oscillation develops, the trade winds diminish and then reverse, leading to an eastward movement of warm water along the equator. The surface waters of the central and eastern Pacific become warmer, and storms over land may increase.

In a non-El Niño year, normally the air and surface water flow westward, the thermocline rises, and upwelling of cold water occurs along the west coast of Central and South America.

El Nino/Southern Oscillation
Effects of El Nino

Chapter 9 - Summary

Ocean water circulates in currents caused mainly by wind friction at the surface and by differences in water mass density beneath the surface zone.

Water near the ocean surface moves to the right of the wind direction in the Northern Hemisphere, and to the left in the Southern Hemisphere.

The Coriolis effect modifies the courses of currents, with currents turning clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere. The Coriolis effect is largely responsible for the phenomenon of westward intensification in both hemispheres.

Upwelling and downwelling describe the vertical movements of water masses. Upwelling is often due to the divergence of surface currents; downwelling is often caused by surface current convergence or an increase in the density of surface water.
El Niño, an anomaly in surface circulation, occurs when the trade winds falter, allowing warm water to build eastward across the Pacific at the equator.

La Niña impacts on the global climate:
- In the U.S., winter temperatures are warmer than normal in the Southeast, and cooler than normal in the Northwest.
- Global climate La Niña impacts tend to be opposite those of El Niño impacts. In the tropics, ocean temperature variations in La Niña tend to be opposite those of El Niño.
- At higher latitudes, El Niño and La Niña are among a number of factors that influence climate. However, the impacts of El Niño and La Niña at these latitudes are most clearly seen in wintertime.
- In the continental U.S., during El Niño years, temperatures in the winter are warmer than normal in the North Central States, and cooler than normal in the Southeast and the Southwest.
- During a La Niña year, winter temperatures are warmer than normal in the Southeast and cooler than normal in the Northwest.
- An anomaly is the value observed during El Niño or La Niña subtracted from the value in a normal year.

Chapter 9 - Summary