REMINDERS:

Problem Set 2: Due this Friday (Feb 1)

Midterm 1: Next Wednesday, Feb 6
- Lecture material covering chapters 1-5
- Multiple Choice, a few Short Answers, a few Definitions
- Practice midterm will be on course website
- Closed-book, no notes, no calculator.
- No scantron necessary

UPCOMING REVIEW SESSION:
- Tuesday, Feb 5, 6:30-8:00pm in CSB 002
Stability

Stable equilibrium

Unstable equilibrium
Is the Atmosphere Stable or Unstable?

Question we ask to see if air will rise.

If air rises, clouds may form.

Stable: Air parcel pushed up a little, but returns to original level

Unstable: Air parcel pushed up a little, and continues to rise.
Clicker Question

Which of these situations is more unstable?

(A) cold air, warm air
(B) warm air, cold air
Also must consider that as air moves up (or down) in the atmosphere, it's temperature will change.

==> changes in pressure cause expansion or compression
Clicker Question

If no condensation takes place, rising air will cool at a rate of approximately 10°C/km. What would happen **IF** condensation was taking place within the rising air parcel?

(A) the air parcel would cool at a faster rate

(B) the air parcel would cool at a slower rate (or may even warm)

(C) would have no impact on cooling rate
An air parcel at the surface has a temperature of 30°C and a dew point temperature of 20°C. Assume dry adiabatic lapse rate = 10°C/km.

\[ T = 30°C, \quad T_{DEW} = 20°C, \quad \Gamma_{DRY} = 10°C/km \]

Assuming \( T_{DEW} \) does not change, at what height will condensation start forming as the air rises?

(A) 0.5 km
(B) 1.0 km
(C) 1.5 km
(D) 2.0 km
Continuation of last question:
Condensation begins at 1 km (this is cloud base) where T=20°C. The air continues to rise to 2 km (this is cloud top).
What is the air temperature at 2 km?

\[ \Gamma_D = 10^\circ C/km, \quad \Gamma_M = 6^\circ C/km \]

(A) 10°C
(B) 14°C
(C) 20°C
(D) 30°C
- **Rising unsaturated** air **cools** at Dry Adiabatic Lapse Rate $\Gamma_D=10^\circ\text{C}/\text{km}$
- **Rising saturated** air **cools** at Moist Adiabatic Lapse Rate $\Gamma_M=6^\circ\text{C}/\text{km}$
- **Sinking** air **warms** at Dry Adiabatic Lapse Rate $\Gamma_D=10^\circ\text{C}/\text{km}$
- **Rising unsaturated** air **cools** at Dry Adiabatic Lapse Rate $\Gamma_D = 10^\circ C/km$
- **Rising saturated** air **cools** at Moist Adiabatic Lapse Rate $\Gamma_M = 6^\circ C/km$
- **Sinking** air **warms** at Dry Adiabatic Lapse Rate $\Gamma_D = 10^\circ C/km$

**Stability Test Case 1** $\Gamma_E = 4^\circ C/km$

$\Gamma_E = 4^\circ C/km$

**Environment**

1000 m $\quad 26^\circ C$

0 m $\quad 30^\circ C$
- Rising unsaturated air cools at Dry Adiabatic Lapse Rate $\Gamma_D=10^\circ\text{C}/\text{km}$
- Rising saturated air cools at Moist Adiabatic Lapse Rate $\Gamma_M=6^\circ\text{C}/\text{km}$
- Sinking air warms at Dry Adiabatic Lapse Rate $\Gamma_D=10^\circ\text{C}/\text{km}$

**Stability Test Case 1 $\Gamma_E=4^\circ\text{C}/\text{km}$**

<table>
<thead>
<tr>
<th>Environment</th>
<th>Rising Air (dry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 m —</td>
<td>26$^\circ$C</td>
</tr>
<tr>
<td>0 m —</td>
<td>30$^\circ$C</td>
</tr>
</tbody>
</table>

Parcel colder than surroundings
$\Rightarrow$cold air more dense than warm air
$\Rightarrow$parcel sinks back down
$\Rightarrow$Stable (returns to starting point)
- **Rising unsaturated** air **cools** at Dry Adiabatic Lapse Rate $\Gamma_D=10^\circ\text{C}/\text{km}$
- **Rising saturated** air **cools** at Moist Adiabatic Lapse Rate $\Gamma_M=6^\circ\text{C}/\text{km}$
- **Sinking** air **warms** at Dry Adiabatic Lapse Rate $\Gamma_D=10^\circ\text{C}/\text{km}$

**Stability Test Case 2** ($\Gamma_E=14^\circ\text{C}/\text{km}$)

\[ \Gamma_E=14^\circ\text{C}/\text{km} \]

**Environment**

1000 m — 16°C

0 m — 30°C
- Rising unsaturated air cools at Dry Adiabatic Lapse Rate $\Gamma_D=10^\circ\text{C}/\text{km}$
- Rising saturated air cools at Moist Adiabatic Lapse Rate $\Gamma_M=6^\circ\text{C}/\text{km}$
- Sinking air warms at Dry Adiabatic Lapse Rate $\Gamma_D=10^\circ\text{C}/\text{km}$

### Stability Test Case 2 ($\Gamma_E=14^\circ\text{C}/\text{km}$)

\[
\begin{array}{ccc}
\text{Environment} & \text{Rising Air (dry)} & \\
\hline
1000 \text{ m} & 16^\circ\text{C} & 20^\circ\text{C} \\
0 \text{ m} & 30^\circ\text{C} & 30^\circ\text{C} \\
\end{array}
\]

Parcel warmer than surroundings
⇒ warm air less dense than cold air
⇒ parcel continues to rise
⇒ **Unstable**
- **Rising unsaturated** air cools at Dry Adiabatic Lapse Rate $\Gamma_D = 10^\circ C/km$
- **Rising saturated** air cools at Moist Adiabatic Lapse Rate $\Gamma_M = 6^\circ C/km$
- **Sinking** air warms at Dry Adiabatic Lapse Rate $\Gamma_D = 10^\circ C/km$

**Stability Test Case 2A ($\Gamma_E = 14^\circ C/km$)**

$\Gamma_E = 14^\circ C/km$

<table>
<thead>
<tr>
<th>Environment</th>
<th>Rising Air (moist, RH=100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000 m — 16°C</td>
<td>24°C, Parcel warmer than surroundings ⇒ warm air less dense than cold air ⇒ parcel continues to rise ⇒ <strong>Unstable</strong></td>
</tr>
<tr>
<td>0 m — 30°C</td>
<td>30°C, If parcel was saturated (RH=100%) ⇒ parcel temp = 24°C at 1000 m ⇒ parcel even warmer ⇒ more unstable ⇒ <strong>more moisture = more unstable</strong></td>
</tr>
</tbody>
</table>
\[ \Gamma_{\text{DRY}} (10^\circ \text{C}/\text{km}) \]

\[ \Gamma_M (6^\circ \text{C}/\text{km}) \]
$$\Gamma_{\text{DRY}} \quad (10^\circ \text{C/km})$$

$$\Gamma_M \quad (6^\circ \text{C/km})$$

$$\Gamma_{\text{ENV}} \quad (4^\circ \text{C/km})$$
\[ T_D < T_E \]
\[ T_M < T_E \]
\[ \Rightarrow \text{STABLE} \]
Γ
DRY
(10°C/km)

Γ
ENV
(14°C/km)

Γ
M
(6°C/km)

Stable
\[ \Gamma_{\text{DRY}} (10^\circ C/\text{km}) \]

\[ \Gamma_{\text{ENV}} (14^\circ C/\text{km}) \]

\[ \Gamma_M (6^\circ C/\text{km}) \]

\[ T_D > T_E \]

\[ T_M > T_E \]
$\Gamma_{\text{DRY}}$ (10°C/km)

$\Gamma_{\text{ENV}}$ (14°C/km)

$T_D > T_E$

$T_M > T_E$

$\Rightarrow$ UNSTABLE
\[ \Gamma_{\text{DRY}} (10^\circ \text{C/km}) \]

\[ \Gamma_{\text{ENV}} (8^\circ \text{C/km}) \]

\[ \Gamma_{\text{M}} (6^\circ \text{C/km}) \]
\( \Gamma_{\text{ENV}} (8^\circ \text{C/km}) \)

\( \Gamma_{\text{DRY}} (10^\circ \text{C/km}) \)

\( \Gamma_{\text{M}} (6^\circ \text{C/km}) \)

Unstable

Stable

\( T_D < T_E \quad T_M > T_E \)

\( T_D \quad T_E \quad T_M \)
\[ \Gamma_{\text{ENV}} (8^\circ\text{C/km}) \]
\[ \Gamma_{\text{DRY}} (10^\circ\text{C/km}) \]
\[ \Gamma_{\text{M}} (6^\circ\text{C/km}) \]

\[ T_D < T_E \]
\[ T_M > T_E \]

\[ \Rightarrow \text{STABLE or UNSTABLE???} \]
Temperature

Height

Conditionally Unstable

Γ_DRY (10°C/km)

Γ_M (6°C/km)

Unstable

Stable