Lightning

**lightning**: an electrical discharge in the atmosphere
Lightning

lightning: an electrical discharge in the atmosphere

- cloud-to-cloud (80%)
- cloud-to-ground (20%)
Fundamentals of electricity

Electrostatics

- Electrical charges are either positive or negative
- Charge is measured in Coulombs
- It takes $6 \times 10^{19}$ electrons to have one Coulomb of charge
- An electrical force exists whenever there is an unequal amount of positive and negative charges
- An electrical force is created when charges are transferred from one material to another
- Electrical charge is conserved (it is neither created or destroyed)
Properties of electricity

\( q \) is the symbol for charge

**current**: measure of charge flow \( (I = \Delta q/\Delta t) \)

**voltage**: potential difference between a negatively charged object and a positively charged one (like terminals on a battery); also the electric potential
Voltage = electric potential ≠ electric potential energy

- electrical energy and electrical potential (www.regentsprep.org)
- electric potential energy is equal to the work done to move charges
- electric potential is the electric potential energy per charge!
- voltage is the same as electric potential
- electric potential is not the same as electric potential energy!
- electric potential exists when there is charge separation
Clicker question

You have a 1.5 V “AA” battery and a 1.5 V “D” cell battery. Which one does more work for each Coulomb worth of charge that moves from the negative to the positive terminal?

A. AA
B. D
C. they perform the same amount of work per Coulomb
D. not enough information given
Clicker question

You have a 1.5 V “AA” battery and a 1.5 V “D” cell battery. Which one has more Coulombs worth of charge stored in the cell?

A. AA  
B. D  
C. they have the same amount charge  
D. not enough information given
Clicker question

You have a 1.5 V battery and a 12 V battery. Which one does more work for each Coulomb worth of charge that moves from the negative to the positive terminal?

A. 1.5 V  
B. 12 V  
C. they perform the same amount work per Coulomb  
D. not enough information given
Clicker question

You have a 1.5 V battery and a 12 V battery. Which one has more Coulombs worth of charge stored in the cell?

A. 1.5 V
B. 12 V
C. they have the same amount of charge stored in the cell
D. not enough information given
Charge separation in the atmosphere

Ionosphere

Earth
Charge separation in the atmosphere

An **electric field** results from the charge difference between atmosphere and the surface of the earth (fair weather electric field)

![Diagram of charge separation in the atmosphere](image)
Proposed charging mechanism in thunderstorms

- Electric field polarizes graupel particles

Saunders 2008
Proposed charging mechanism in thunderstorms

- Electric field polarizes graupel particles
- smaller ice particles collide and strip off the positive charge
- ice particle travels to the top of the cloud

Saunders 2008
Proposed charging mechanism in thunderstorms

Fig. 4  The charging a graupel particle (soft-hail pellet) during droplet accretion (riming) and ice crystal rebounding collisions. (Emersic 2006)

Saunders 2008
Charge separation in cloud
Clicker question

Why don’t charges just flow continuously through the air and neutralize the atmosphere?

A. the negatively charged surface repels the negative charges at the cloud base

B. air is a good electrical insulator

C. it does

D. nobody knows
Lightning via a stepped leader

(a)  

(b)  

(c)  

(d)
Lightning: cloud to ground

1. charge separation within the cloud enhances the electric field between the earth and the atmosphere
2. electric field begins to “break down” air between
3. **stepped leader** of negative charges forms from cloud toward ground
4. **positive streamer** of positive charges form from ground to cloud
5. stepped leader and positive streamer meet, forming a conduit for charge transfer between cloud and ground
more info

- Langmuir Lab at NMT
Clicker question

A. Cloud to ground lightning is always initiated with negative charges in the stepped leader moving toward ground.

B. Discharges in the electric field can happen without lightning going all the way to the ground.

C. A bolt from the blue is a figure of speech, not an actual phenomenon.

D. Sprites and blue jets are creatures in faerie tales, not electrical phenomena.
Thunder

- electric current traveling in the lightning path heats the air until it explodes
- the shockwave from the explosion is a compression wave, or sound wave, that we call thunder
**Lightning safety**

- Go inside (buildings or vehicles)
- avoid tall, high or exposed areas
- avoid open spaces
- avoid water
- NOAA Lightning safety
Clicker question

Air mass thunderstorms

A. are thunderstorms which occupy an entire air mass
B. are rare, but extremely destructive
C. only last 10s of minutes because they create downdrafts which cut off their moisture supply
D. occur near frontal boundaries
Air mass thunderstorms

**Air mass thunderstorms**: consist of a number of individual convective updrafts (*cells*)

The life cycle of an air mass thunderstorm:

1. cumulus stage
2. mature
3. dissipative
Air mass thunderstorm life cycle

Air is uplifted, creating initial clouds which pre-moisten the environment
Cumulus stage

During the cumulus stage,

- temperature decreases with height at the sat’d adiabatic lapse rate
- some of the cloud extends above the freezing level
- ice crystals form and grow by the Bergeron process
- the sky darkens below the thickening cloud & precipitation begins to fall
Air mass thunderstorm life cycle

Air is uplifted, creating initial clouds which pre-moisten the environment.

Heavy rain or graupel particles drag air toward the surface creating downdrafts in the areas of most intense precipitation.
Mature stage

During the mature stage,

- precipitation, lightning and thunder are most intense
- the top of the cloud extend to stable layers of the atmosphere which prevent further uplift
- strong winds at top layers push ice particles to create the classic thunderstorm anvil
- updrafts dominate the interior of the cloud, downdrafts occur just outside the cloud boundary (perfect conditions for turbulence which entrain dry air into cloud)
Air mass thunderstorm life cycle

- Air is uplifted, creating initial clouds which pre-moisten the environment.
- Heavy rain or graupel particles drag air toward the surface, creating downdrafts in the areas of most intense precipitation.
- Downdrafts eventually occupy the entire cloud base, cutting off the supply of moisture.
Dissipative stage

During the dissipative stage,

- supply of moisture is cutoff by downdrafts associated with heavy precipitation
- precipitation diminishes, sky clears
- the cloud boundary “blurs” and becomes “fuzzy”; this is associated with glaciation
Clicker question

A. The glaciated parts of the cloud contains a mixture of ice crystals and supercooled water droplets.

B. Only about 20% of the condensed moisture in a cloud falls as precipitation.

C. Few lightning events are associated with air mass thunderstorms.

D. Air mass thunderstorms only support one convective cell at a time.
Severe thunderstorms: definition

severe thunderstorms have

- wind speeds that exceed 93 km/hr (58 mph)
- hailstones larger than 1.9 cm in diameter
- or they spawn tornadoes
Severe thunderstorms: characteristics

In severe thunderstorms

- downdrafts reinforce convective updrafts and thus intensify the storm
- are **mesoscale** phenomena (it has a size ranging from 10’s to 100’s of km)
- can involve a cooperation of convective cells which cluster; these are called **mesoscale convective systems (MCSs)**
- MCSs can last from 12 hours to several days
- can arise from **supercells**, which is made of a single updraft region (rather than a collection of smaller cooperating cells)
How do downdrafts reinforce updrafts in MCSs?

Strong downdrafts associated with precipitation generate outflow that hits the surrounding warmer air, causing the warm air to rise and thus reinforce updraft for another convective cell.
How do downdrafts reinforce updrafts in MCSs?

Strong downdrafts associated with precipitation
How do downdrafts reinforce updrafts in MCSs?

Strong downdrafts associated with precipitation generate outflow that hits the surrounding warmer air.
How do downdrafts reinforce updrafts in MCSs?

Strong downdrafts associated with precipitation generate outflow that hits the surrounding warmer air, causing the warm air to rise and thus reinforce updraft for another convective cell.
Generation of new cells in a mesoscale convective complex (MCC)
Squall lines

- Linear band of individual storm cells (500 km long)
- Usually form in warm sector of midlatitude cyclone in front of the cold front
- Looking for squall lines
Role of wind shear in squall lines
Clicker question

Supercell storms

A. have diameters from 20-50 km
B. are usually more violent than MCCs or squall lines, even though they are smaller
C. consist of a single extremely powerful cell rather than a collection of smaller cells
D. are described by all of the above
Tornadoes

- yesterday’s news
- archive surface analysis
- yesterday’s official storm report
Clicker question

Which of the following statements about tornadoes is false?

A. Strong tornadic winds result from extremely large pressure gradients (100 mb/.1 km, compared to 35 mb/1000 km difference in sea level pressure across North America).

B. The wind speed can be measured directly in a tornado (105-450 km/hr, or 65-280 mph).

C. They can span a wide range of sizes and last from minutes to hours.

D. They normally travel northeastward at about 50 km/hr (30 mph), more or less.
Tornado Safety

- Stay inside, in a basement
- If no basement, go to interior of house. Cover yourself with a mattress.
- Evacuate a mobile home! If no fixed building exists, lie flat in the ground away from the mobile home.
- If driving, try to avoid tornado by driving at right angles to path (they move southwest to northeast).
- If you cannot avoid path while driving, abandon vehicle and seek nearby shelter or run low to the ground away from road.
Tornado formation

- need a mesocyclone (large vortex, example of how to get one shown in figure)
- contraction of the mesovortex to a smaller vortex increases windspeed by conservation of angular momentum
- tornado genesis is actually not well understood
NMT on Nova

- NOAA Lightning safety