Physics 535 Physics of Lightning – Syllabus
Text: The Lightning Discharge (Uman)
Readings:

1. Are from books on reserve in the library
2. Are handed out in class
3. If available electronically, are posted on the course web-site (http://www.physics.nmt.edu/~rsonnenf/phys535/phys535.html)

PART I - LIGHTNING PHENOMENA AND PROCESSES
Introduction –

READ - Uman – Chapters 1 – Introduction 1-36
Uman – Chapter 2 – Lightning Phenomenology 37-58
Uman64, Wilson25, Shonland37, Standler79,
Christian02

PROBLEMS – Due 8/29 :
1) Assuming a charge of 1 C / kilometer, how large is a lightning channel?
2) Assume the electrosphere is as described by Uman on p. 30, with the implication that the Earth can be modeled as a large parallel plate capacitor with concentric spherical electrodes. What is the effective gap in the electrodes? Does this make sense?
3) Given an average discharge current of 1000A, how long should the electrosphere stay charged?
4) What does this tell you about atmospheric conductivity?
5) What are typical ionic mobilities?

PROBLEMS – Due 9/5

Bring in 5 or 6 problems suggested to you by the readings.
Be able to demonstrate a solution to a couple of them.

READING SUMMARIES – Due 9/5 (Summarize Uman64, Schonland37, Wilson25, Christian02, and Stander79)
Summaries should summarize the important points of the paper. If they connect the results between papers, so much the better. If they raise questions, possibly non-numerical, fine. If the summary is better captured by some cartoon of a physical process, this is also fine. Select one of these papers to present to the class in 10 minutes or less.

Uman64 – Will Walden-Newman
Standler79 – JoAnna Johnston
Christian02 – Sonja Behnke
Wilson25 – Nick Targhetta
Schonland37 – Mike Stock

READ (for 9/10) - Uman – Chapters 3-4 --
READ (for 9/12) – Winn74, Marshall91, Williams89

PROBLEMS – Due 9/10

1) At time t=0, a uniform charge density ρ_o exists in the center of a spherical conductor of finite conductivity σ. The charge may be assumed to be constant over a sphere of radius r. Call the total charge contained within r, Q_0 . The radius of the entire conductor is R. Find and solve the differential equation describing the total charge Q contained within "r" as a function of time. [Mike Stock's question suggested this, and problem 2]

2) At time t=0, a uniform charge density ρ_o exists on an infinite flat slab inside a conductor of finite conductivity σ. Take some finite section of that slab of area A and come up with an expression describing the total charge Q on that slab as a function of time.

3) Assume the tripole model of a storm given by Uman on p. 59. Derive analytical expressions for the electric field on the ground and use Matlab (or whatever tool you like) to plot the field vs. position and reproduce figure 3.2. [Will Walden's question suggested this]

4) Your analysis for #3 showed that there are no x and y components of E-field on the ground. You analyzed three cases for lower positive charge of 0, 5 and 10 Coulombs. Repeat the analysis for the case of Q-lower-positive=0, but do it for a plane 2 km above the ground. Now you'll need two plots, one for the z-component of E and one for the x-component.

Students are asked to compose six problems/week based on the readings.

The student should know how to solve three of them. The others can be more "interesting", and they may be vaguely defined. We can discuss them in class and see if they can become better defined or solvable.

Students are also asked to locate and review an additional paper/week on a topic of interest and present the principal results to the class.

Grades – The course grade is primarily based on participation and homework. The expectation is that we all will be present and involved and diligent about solving problems and helping each other clarify this complex area.

Week 2-3 – Electric Field measurements and Lightning –

READ - Uman – Chapters 3-6 (pp. 58-98) Cloud and Lightning Charges, Preliminary Breakdown, Stepped Leader

Week 4-5 – Electric Field measurements and Lightning –

READ – Uman75 - The electromagnetic radiation from a Finite Antenna.

- Brook62, -- Coleman03

ANALYSIS: Calculate charge profile from raw balloon sounding

MODELING: Calculate electric and magnetic fields on the ground vs. time for current pulse given in Uman75, reproduce Figure 3 therefrom.

PROBLEMS:

What is the mobility of a diatomic molecule of mass M?

(Derive from first principles).

What is the mobility of a water droplet of radius R?

What should be recombination rate of ions with hydrometeors?

How much should a lightning stroke perturb the sounding profile of electric field in a storm?

ANALYSIS: Calculate charge profile from raw balloon sounding

MODELING: Calculate electric fields on the ground vs. time for

Different assumptions about storm charge structure. Reproduce Moore et al.

Week 6-7 – Charging Mechanisms

The Thundercloud (Golde – Ch. 4)

Jayaratne84, Saunders93, Saunders94, Workman67, Wilson56

MODELING:

What is the charge distribution induced on a dielectric sphere?

What force does that sphere feel in a gradient?

Calculate inductive charging rates assuming fixed updraft and droplet sized distributions.

Calculate non-inductive charging rates with Saunders model.

Week 8 – Return Stroke, Dart Leaders and Continuing Current –

READ - Uman – Chapters 7-9 (pp. 99-178) Return Stroke, Dart Leader, Continuing Current

MODELING: Reproduce Results of Lin80.

Week 9 – J, K, Processes, Positive Lightning, Lightning Triggering

READ - Uman – Chapters 10-12 (pp. 179-230)

MODELING: Reproduce data of Krehbiel79

PART II – PLASMA PHYSICS AND THE LONG SPARK

Week 10 – Concepts and calculations for ionized gasses

a) Mean free-path, cross-section, recombination time, impact excitation.

b) Thermal diffusion and mobility in an electric field.

c) Rarefied gasses and breakdown thresholds – the Townsend effect

d) Self sustaining discharges

READ – Penning57 – Gas Discharge – pp. 1-40

READ – Millikan – Appendix A (Mobilities and Diffusion Coefficients)

Appendix E – (Molecular X-section and Mean Free Path)

Week 11 -- Ions in the atmosphere

a) Small ions and large ions

b) Effect of electric field on collision probability

c) Avalanche Ignition and Space Charge ignition

READ – Israel – Atmospheric Electricity, Vol. 1 – pp. 58-65. "Avalanche Ignition and Space Charge Ignition"

MODELING – Calculate recombination rate vs. pressure for electrons and singly charged Nitrogen molecules.

Week 12-15 Bazelyan and Raizer

READINGS

*Beasley00, William H. Beasley and Kenneth B. Eack and Heidi E. Morris and W. David Rust and Donald R. MacGorman, Electric-field changes of lightning observed in thunderstorms, GRL, V27, pp189-92.

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Black63, -- J.F. Black, Weather control: Use of asphalt coatings to tap solar energy, Science, 226-227 (1963).

Brook60a - Brook and Kitagawa, "Some aspects of lightning activity and related meteorological conditions", JGR, V65, 1203-10 (1960).

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Brook60c - M. Brook and N. Kitagawa, "Electric-field changes and the design of lightning-flash counters", JGR, V65, 1927-31 (1960).

*Brook62 - M. Brook, N. Kitagawa, and E. Workman "Quantitative study of strokes and continuing currents in Lightning Discharges to Ground", JGR, V67, 649-59 (1962).

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*Christian03 -- Hugh Christian et al., “Global Frequency and Distribution of Lightning as Observed from Space by the Optical Transient Detector”, JGR, V108, doi:10.1029/2002JD002347, (2003).

*Coleman03 -- L. M. Coleman and T. C. Marshall and M. Stolzenburg and T. Hamlin and P. R. Krehbiel and W. Rison and R. J. Thomas, Effects of charge and electrostatic potential on lightning propagation, JGR, V108, pp12-1 12-27

*Eack00 – K. Eack et al., “Gamma Ray Emissions Observed in a Thunderstorm Anvil”, GRL, V.27, pp 185-188.

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Gurevich94 – Gurevich, A.V., G.M. Milikh, and R. Roussel-Dupre, “Nonuniform runaway air-breakdown”, Phys. Lett. A, V.187, pp 197-203, (1994)

Jayaratne84, E. R. Jayaratne and C. P. R. Saunders}, The ``rain gush,'' lightning, and the lower positive charge center in thunderstorms, JGR, v89, 11816-18

*Krehbiel79, Paul R. Krehbiel and Marx Brook and Roy A. McCrory, An analysis of the charge structure of lightning discharges to ground, JGR, V84, pp2432-56, 1979

Marshall91 T.C. Marshall and W.D. Rust, "Electric Field Soundings Through Thunderstorms", JGR, V96, 22297-22306, (1991).

Lin80 Y.T. Lin, M.A.Uman and R.B. Standler, "Lightning Return Stroke Models", JGR, V85, 1571-83, (1980).

Master81 M.J. Master, M.A. Uman, Y.T. Lin, and R.B. Standler, "Calculations of Lightning Return Stroke electric and magnetic fields above ground", JGR, V86, 12127-32, (1981).

Malan63 - Malan, D.J., Physics of Lightning, The English Universities Press, Ltd, London, 1963.

Ogawa64, T. Ogawa and M. Brook, The Mechanism of Intracloud lightning discharge, JGR, 69:5141-50 (1964)

Orville67, R.E.Orville, M.A.Uman and A.M.Sletten, Temperature and Electron Density in Long Air sparks, J.Appl. Phys. 38:895-896 (1967)

*Penning57, Electrical Discharges in Gases, Phillips' Technical Library, Holland, 1957.

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Roussel Dupre et al.xx, Relativistic Runaway Breakdown

Saunders94, C. P. R. Saunders},Thunderstorm electrification laboratory experiments and charging mechanisms, JGR, V99, 10773-79.

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*Standler79, R. B. Standler and W. P. Winn, Effects of coronae on electric fields beneath thunderstorms, QJRMS, v105, pp285-302

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*Uman75 – M.A. Uman, D.K. McLain and E.P. Krider, The electromagnetic radiation from a finite antenna, Am. J. Phys. Vol 43, pp.33-38, 1975

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Ward65, Calculations of Electrical Breakdown in Air at Near-atmospheric Pressure, Phys Rev., 138:A1357-62

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* Workman67 - E.J. Workman, The Production of Thunderstorm electricity, J. Franklin Institute, V283:540-557, (1967)

Worked problems – Model leader propagation – Return stroke propagation.

Rel. Run. Breakdown
Moore 2001 (EnergeticRadiaion --)
Marshall2005 Observed Electric fields associated with ...

Electric Field soundings thru Thunderstorms (Marshall and Rust)

Questions that came up in class:

1) How do you determine speed of leaders – Mike Stock (checking Boys camera).

   Attachment process (Sonja) – Is it affected by + vs. - lightning? (To be determined)

Krehbiel invited?
Keack invite?
Sonnenfeld's talk
Gross invite.