

Chapter 14: Thunderstorms

N52e)

Given a lightning discharge current (kA) below and a voltage difference between the beginning to end of the lightning channel of  $10^{10}$  V, find (1) the resistance of the ionized lightning channel and (2) the amount of charge (C) transferred between the cloud and the ground during the 20 microsecs lifetime of the lightning stroke.  
e. 10

Given: Lightning discharge current = 10 kA = 10000 A  
Voltage difference =  $1.00E+10$  V  
Lifetime of lightning stroke = 20 microseconds =  $2.00E-05$  s

Find: Resistance of ionized lightning channel = ?  
Charge transferred between cloud and ground = ? C

Using the equation  $\Delta V = I R$ ,

$$R = V / I$$

$$R = 1.00E+06 \text{ ohm}$$

And  $1 \text{ A} = 1 \text{ C per second}$

Amount of charge transferred = lightning discharge current \* lifetime

$$\text{Charge} = 0.20 \text{ C}$$

Check: Units OK. Physics OK.

N53e)

What voltage differences is needed to cause lightning for both (1) dry air, and (2) cloudy air, given a lightning stroke length (km) of:  
e. 1

Given: Lightning stroke length,  $\Delta z = 1 \text{ km}$   
 $B_{\text{dry}} = 3.00E+09 \text{ V/km}$   
 $B_{\text{cloudy}} = 1.00E+09 \text{ V/km}$

Find: Voltage differences,  $\Delta V_{\text{dry}} = ? \text{ V}$   
Voltage differences,  $\Delta V_{\text{cloudy}} = ? \text{ V}$

Using eq. 14.42,

$$\Delta V = B * \Delta z$$

	B	$\Delta V$
Dry air	3.00E+09	3.00E+09
Cloudy	1.00E+09	1.00E+09

Check: Units Ok. Physics Ok.

N58e)

If lightning heats the air to the temperature (K) given below, then plot (on a log-log graph) the speed (Mach number), pressure (as ratio relative to background pressure), and radius of the shock front vs. time given ambient background pressure of 100 kPa and temperature 20 degs C.  
e. 20,000

Assume initial radius of shock is = 15 cm

Given:  $T_a = 20000$  K  
 $P_b = 100$  kPa = 100000 Pa  
 $T_b = 20$  degs C = 293.15 K

Find: Mach number = ?  
 $P_a/P_b = ?$   
 Radius of shock front = ? m  
 Plot versus time.

(Following solved example on Pg. 557)

Because the phenomenon happens in a very short time scale and also nonlinearly, we will use a constant ratio of the shock front radius as the increment of the iteration.

Increment the radius of the shock front for each iteration by:

$$r_{\text{new}} / r_{\text{old}} = 1.05$$

Using equation (14.51), time needed for radius to grow by 5% is

$$r_{\text{new}} - r_{\text{old}} = C * dt \quad -14.51$$

$$dt = (r_{\text{new}} - r_{\text{old}}) / C$$

$$t_{\text{new}} - t_{\text{old}} = (r_{\text{new}} - r_{\text{old}}) / C$$

So,  $t_{\text{new}} = t_{\text{old}} + (r_{\text{new}} - r_{\text{old}}) / C$

To find  $P_a/P_b$ , need to know  $T_a/T_b$ .

$$P_a / P_b = T_a / T_b \quad -14.56$$

To find Ma, use eq. 14.47:

$$Ma = \sqrt{((P_a / P_b)^6 + 1) / 7}$$

To find C, use eq. 14.50:

$$C = Ma * sb$$

And, using eq. 14.49,

$$sb = as * (T_b)^{0.5}$$

where  $as = 20$  m/s K<sup>-1/2</sup>

So,  $sb = 342.43248$  m/s

To find  $T_a(\text{new})$ , need to find  $T_e$  first which is given by eq.14.53:

$$T_e = T_b * (5 + Ma^2)(7 Ma^2 - 1) / (36 Ma^2)$$

And  $T_a(\text{new})$  is then, using eq. 14.54:

$$T_{a_{\text{new}}} = T_e + (T_{a_{\text{old}}} - T_e) / (r_{\text{new}} / r_{\text{old}})^2$$

Iterate until air temperature goes back to background temperature.

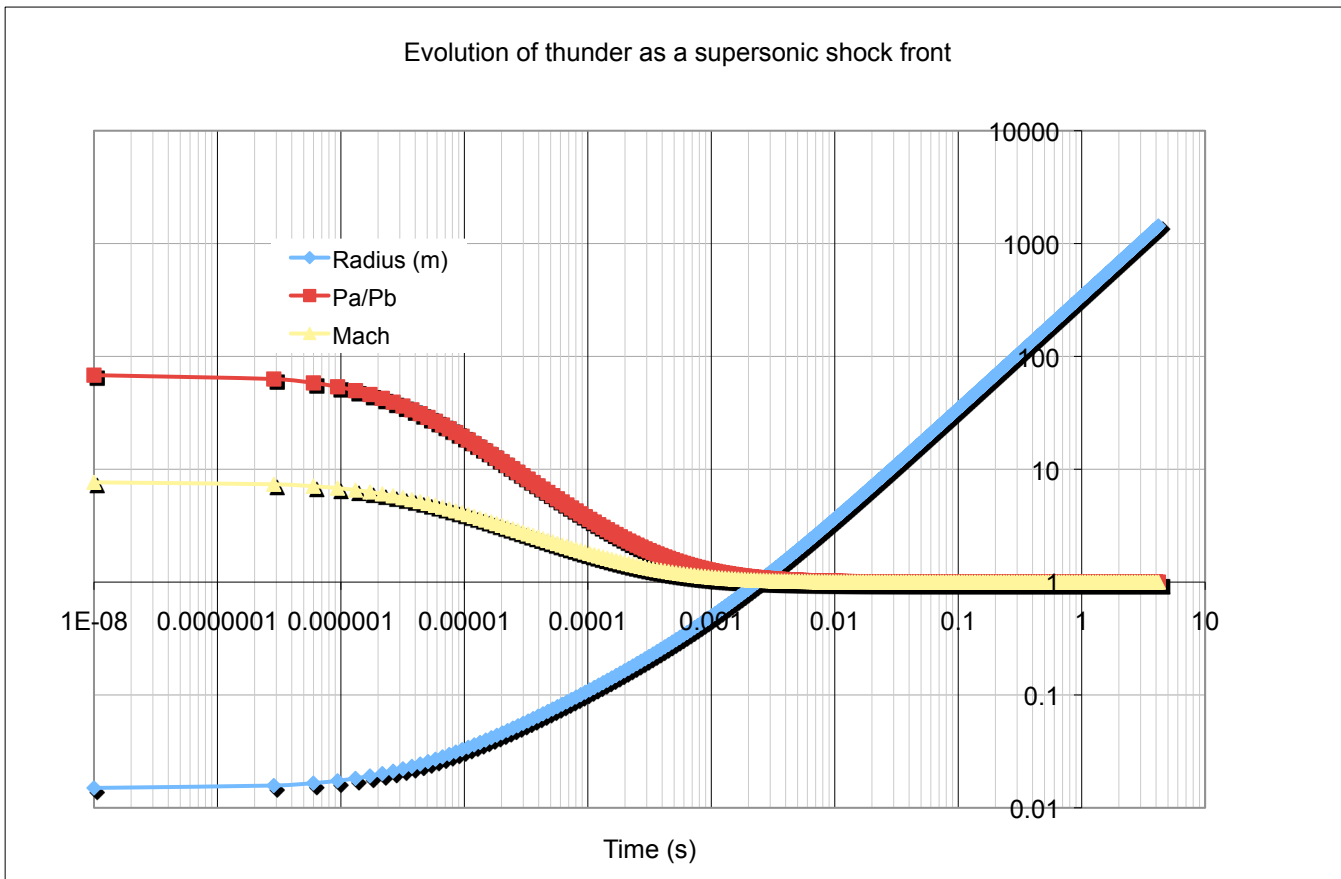
radius of shock front							
(m)	time (s)	$T_a$ (K)	$P_a / P_b$	Ma	C (m/s)	$T_e$ (K)	
0.015	0	20000	68.224458	7.656433	2621.811	3617.6	
0.01575	2.8606E-07	18476.924	63.028907	7.359866	2520.257	3363.7	
0.0165375	5.9853E-07	17071.844	58.235864	7.075261	2422.799	3129.5	
0.017364375	9.3982E-07	15775.617	53.814145	6.802152	2329.278	2913.4	
0.018232594	1.3126E-06	14579.809	49.73498	6.540095	2239.541	2714	
0.019144223	1.7196E-06	13476.641	45.971827	6.288663	2153.442	2530.1	
0.020101435	2.1641E-06	12458.934	42.500201	6.047446	2070.842	2360.4	
0.021106506	2.6495E-06	11520.066	39.297515	5.81605	1991.604	2203.8	
0.022161832	3.1794E-06	10653.93	36.342929	5.594099	1915.601	2059.4	
0.023269923	3.7578E-06	9854.8881	33.61722	5.381228	1842.707	1926.1	
0.024433419	4.3892E-06	9117.7428	31.102653	5.177091	1772.804	1803.1	
0.02565509	5.0783E-06	8437.6978	28.782868	4.981354	1705.777	1689.6	

0.026937845	5.8303E-06	7810.3282	26.64277	4.793696	1641.517	1585
0.028284737	6.6509E-06	7231.5521	24.668436	4.613809	1579.918	1488.4
0.029698974	7.546E-06	6697.6039	22.84702	4.441398	1520.879	1399.2
0.031183923	8.5224E-06	6205.0095	21.166671	4.27618	1464.303	1316.9
0.032743119	9.5872E-06	5750.5639	19.616455	4.117883	1410.097	1241
0.034380275	1.0748E-05	5331.3105	18.186289	3.966246	1358.171	1171
0.036099289	1.2014E-05	4944.5215	16.866865	3.821017	1308.44	1106.3
0.037904253	1.3393E-05	4587.6805	15.649601	3.681956	1260.821	1046.6
0.039799466	1.4897E-05	4258.466	14.526577	3.548832	1215.235	991.52
0.041789439	1.6534E-05	3954.7362	13.490487	3.421422	1171.606	940.65
0.043878911	1.8317E-05	3674.5152	12.53459	3.299514	1129.861	893.69
0.046072856	2.0259E-05	3415.98	11.652669	3.182901	1089.929	850.32
0.048376499	2.2373E-05	3177.4491	10.838987	3.071387	1051.743	810.27
0.050795324	2.4673E-05	2957.3708	10.088251	2.964782	1015.237	773.27
0.05333509	2.7174E-05	2754.3138	9.3955785	2.862902	980.3508	739.09
0.056001845	2.9894E-05	2566.9576	8.7564646	2.765574	947.0223	707.51
0.058801937	3.2851E-05	2394.0838	8.1667534	2.672626	915.194	678.32
0.061742034	3.6064E-05	2234.5684	7.6226109	2.583897	884.8102	651.34
0.064829136	3.9553E-05	2087.3745	7.1204998	2.499228	855.817	626.38
0.068070592	4.334E-05	1951.5455	6.6571567	2.418469	828.1623	603.3
0.071474122	4.745E-05	1826.1987	6.2295709	2.341472	801.7959	581.95
0.075047828	5.1907E-05	1710.52	5.834965	2.268095	776.6694	562.18
0.07880022	5.6739E-05	1603.7581	5.4707765	2.198202	752.7359	543.87
0.082740231	6.1973E-05	1505.2201	5.1346414	2.131661	729.9499	526.92
0.086877242	6.764E-05	1414.2668	4.8243792	2.068342	708.2675	511.2
0.091221104	7.3773E-05	1330.3082	4.537978	2.008122	687.6461	496.63
0.095782159	8.0406E-05	1252.8006	4.2735821	1.950879	668.0442	483.11
0.100571267	8.7575E-05	1181.242	4.0294797	1.896496	649.4218	470.56
0.105599831	9.5318E-05	1115.1695	3.8040919	1.84486	631.7399	458.91
0.110879822	0.00010368	1054.1564	3.5959623	1.795859	614.9605	448.08
0.116423813	0.00011269	997.80868	3.4037478	1.749387	599.047	438
0.122245004	0.00012241	945.76337	3.2262097	1.705339	583.9633	428.63
0.128357254	0.00013288	897.68557	3.0622056	1.663612	569.6748	419.91
0.134775117	0.00014414	853.26651	2.9106823	1.624108	556.1474	411.78
0.141513873	0.00015626	812.2215	2.7706686	1.586731	543.3483	404.21
0.148589566	0.00016928	774.28805	2.6412692	1.551387	531.2453	397.14
0.156019045	0.00018327	739.22423	2.5216587	1.517985	519.8074	390.54
0.163819997	0.00019827	706.80702	2.4110763	1.486437	509.0042	384.38
0.172010997	0.00021437	676.83088	2.308821	1.456656	498.8063	378.62
0.180611547	0.00023161	649.10638	2.2142466	1.42856	489.1852	373.24
0.189642124	0.00025007	623.45899	2.1267576	1.402067	480.1133	368.2
0.19912423	0.00026982	599.72788	2.0458055	1.3771	471.5638	363.49
0.209080442	0.00029093	577.7649	1.9708849	1.353583	463.5108	359.08
0.219534464	0.00031348	557.43354	1.9015301	1.331443	455.9293	354.95
0.230511187	0.00033756	538.60809	1.8373123	1.310609	448.7951	351.07
0.242036746	0.00036324	521.17272	1.7778363	1.291014	442.0851	347.44
0.254138584	0.00039062	505.02075	1.7227384	1.272592	435.7768	344.04
0.266845513	0.00041978	490.05394	1.6716832	1.25528	429.8487	340.84
0.280187788	0.00045081	476.18178	1.6243622	1.239019	424.2803	337.85
0.294197178	0.00048383	463.32089	1.5804909	1.22375	419.0517	335.04
0.308907037	0.00051894	451.3945	1.5398073	1.209418	414.144	332.4
0.324352389	0.00055623	440.33184	1.5020701	1.195971	409.5392	329.93
0.340570008	0.00059583	430.06775	1.467057	1.183357	405.22	327.61
0.357598508	0.00063785	420.54215	1.434563	1.17153	401.1699	325.43
0.375478434	0.00068242	411.6997	1.4043995	1.160443	397.3734	323.39
0.394252355	0.00072967	403.48937	1.3763922	1.150053	393.8155	321.47
0.413964973	0.00077972	395.86412	1.3503808	1.140319	390.4821	319.67
0.434663222	0.00083273	388.78056	1.3262172	1.131201	387.3598	317.99
0.456396383	0.00088884	382.19869	1.3037649	1.122662	384.4359	316.4
0.479216202	0.0009482	376.08159	1.2828981	1.114668	381.6984	314.92
0.503177012	0.00101097	370.39517	1.2635005	1.107185	379.1359	313.53
0.528335863	0.00107733	365.10799	1.2454648	1.100181	376.7377	312.22
0.554752656	0.00114745	360.191	1.2286918	1.093628	374.4936	311
0.582490289	0.00122152	355.61737	1.2130901	1.087497	372.3941	309.85
0.611614803	0.00129972	351.36229	1.1985751	1.081761	370.4302	308.77

0.642195543	0.00138228	347.40284	1.1850685	1.076397	368.5932	307.77
0.674305321	0.00146939	343.71783	1.1724981	1.07138	366.8754	306.82
0.708020587	0.00156129	340.28766	1.1607971	1.066689	365.2691	305.94
0.743421616	0.00165821	337.09417	1.1499033	1.062303	363.7672	305.11
0.780592697	0.00176039	334.12056	1.1397597	1.058203	362.3631	304.33
0.819622332	0.0018681	331.3513	1.1303132	1.05437	361.0507	303.61
0.860603448	0.00198161	328.77197	1.1215145	1.050788	359.8239	302.93
0.903633621	0.00210119	326.36921	1.1133181	1.04744	358.6774	302.29
0.948815302	0.00222716	324.13065	1.1056819	1.044311	357.6058	301.7
0.996256067	0.00235982	322.04483	1.0985667	1.041386	356.6045	301.14
1.04606887	0.00249951	320.10108	1.0919361	1.038654	355.6689	300.62
1.098372314	0.00264657	318.28953	1.0857566	1.036101	354.7947	300.13
1.153290929	0.00280136	316.60103	1.0799967	1.033716	353.9779	299.67
1.210955476	0.00296426	315.02705	1.0746275	1.031487	353.2148	299.24
1.27150325	0.00313568	313.55969	1.069622	1.029406	352.5019	298.84
1.335078412	0.00331603	312.19161	1.0649552	1.027461	351.836	298.47
1.401832333	0.00350576	310.91599	1.0606038	1.025644	351.2139	298.12
1.471923949	0.00370533	309.72649	1.0565461	1.023947	350.6328	297.79
1.545520147	0.00391523	308.6172	1.0527621	1.022362	350.09	297.49
1.622796154	0.00413596	307.58266	1.049233	1.020882	349.5831	297.2
1.703935962	0.00436806	306.61775	1.0459415	1.019499	349.1096	296.94
1.78913276	0.00461211	305.71774	1.0428714	1.018208	348.6674	296.69
1.878589398	0.00486867	304.87822	1.0400076	1.017002	348.2544	296.45
1.972518868	0.00513839	304.09508	1.0373361	1.015875	347.8686	296.24
2.071144811	0.0054219	303.36448	1.0348439	1.014823	347.5084	296.03
2.174702052	0.0057199	302.68289	1.0325188	1.013841	347.172	295.84
2.283437154	0.0060331	302.04697	1.0303495	1.012923	346.8579	295.67
2.397609012	0.00636226	301.45365	1.0283256	1.012067	346.5645	295.5
2.517489463	0.00670818	300.90004	1.0264371	1.011267	346.2906	295.34
2.643363936	0.00707167	300.38348	1.024675	1.01052	346.0348	295.2
2.775532132	0.00745362	299.90147	1.0230308	1.009822	345.7959	295.06
2.914308739	0.00785495	299.45167	1.0214964	1.009171	345.5728	294.94
3.060024176	0.00827661	299.03193	1.0200646	1.008562	345.3645	294.82
3.213025385	0.00871962	298.64023	1.0187284	1.007994	345.1701	294.71
3.373676654	0.00918505	298.27467	1.0174814	1.007464	344.9885	294.61
3.542360487	0.009674	297.93352	1.0163177	1.006969	344.8189	294.51
3.719478511	0.01018766	297.61513	1.0152315	1.006507	344.6606	294.42
3.905452437	0.01072724	297.31797	1.0142179	1.006075	344.5127	294.33
4.100725058	0.01129405	297.04063	1.0132718	1.005672	344.3747	294.26
4.305761311	0.01188944	296.78178	1.0123888	1.005295	344.2458	294.18
4.521049377	0.01251483	296.54018	1.0115647	1.004944	344.1255	294.11
4.747101846	0.01317172	296.31468	1.0107954	1.004616	344.0131	294.05
4.984456938	0.01386168	296.1042	1.0100774	1.00431	343.9082	293.99
5.233679785	0.01458636	295.90774	1.0094073	1.004024	343.8103	293.94
5.495363774	0.01534749	295.72436	1.0087817	1.003757	343.7188	293.88
5.770131963	0.01614688	295.55319	1.0081978	1.003507	343.6335	293.83
6.058638561	0.01698646	295.39342	1.0076528	1.003274	343.5537	293.79
6.361570489	0.01786822	295.24427	1.007144	1.003057	343.4793	293.75
6.679649014	0.01879427	295.10506	1.0066691	1.002854	343.4098	293.71
7.013631464	0.01976682	294.9751	1.0062258	1.002665	343.3449	293.67
7.364313038	0.02078819	294.8538	1.005812	1.002488	343.2844	293.64
7.732528689	0.02186081	294.74056	1.0054257	1.002323	343.2278	293.6
8.119155124	0.02298725	294.63485	1.0050652	1.002168	343.175	293.57
8.52511288	0.0241702	294.53617	1.0047286	1.002024	343.1257	293.55
8.951368524	0.02541247	294.44406	1.0044143	1.00189	343.0797	293.52
9.39893695	0.02671703	294.35807	1.004121	1.001765	343.0367	293.49
9.868883798	0.028087	294.2778	1.0038472	1.001647	342.9966	293.47
10.36232799	0.02952562	294.20286	1.0035916	1.001538	342.9592	293.45
10.88044439	0.03103635	294.13291	1.0033529	1.001436	342.9242	293.43
11.42446661	0.03262277	294.06761	1.0031302	1.001341	342.8915	293.41
11.99568994	0.03428867	294.00664	1.0029222	1.001252	342.8611	293.39
12.59547443	0.03603802	293.94973	1.0027281	1.001168	342.8326	293.38
13.22524816	0.03787499	293.8966	1.0025468	1.001091	342.806	293.36
13.88651056	0.03980396	293.847	1.0023776	1.001018	342.7812	293.35
14.58083609	0.04182952	293.8007	1.0022197	1.000951	342.7581	293.34

15.3098779	0.04395651	293.75748	1.0020722	1.000888	342.7365	293.32
16.07537179	0.04618999	293.71712	1.0019346	1.000829	342.7163	293.31
16.87914038	0.04853528	293.67945	1.0018061	1.000774	342.6974	293.3
17.7230974	0.05099797	293.64428	1.0016861	1.000722	342.6798	293.29
18.60925227	0.05358392	293.61145	1.0015741	1.000674	342.6634	293.28
19.53971488	0.0562993	293.5808	1.0014696	1.00063	342.6481	293.27
20.51670063	0.05915059	293.55219	1.0013719	1.000588	342.6338	293.26
21.54253566	0.06214455	293.52547	1.0012808	1.000549	342.6204	293.26
22.61966244	0.06528835	293.50053	1.0011958	1.000512	342.6079	293.25
23.75064556	0.06858945	293.47725	1.0011163	1.000478	342.5963	293.24
24.93817784	0.07205572	293.45552	1.0010422	1.000447	342.5854	293.24
26.18508673	0.07569542	293.43523	1.000973	1.000417	342.5752	293.23
27.49434107	0.07951722	293.41628	1.0009083	1.000389	342.5658	293.23
28.86905812	0.08353022	293.3986	1.000848	1.000363	342.5569	293.22
30.31251103	0.08774399	293.38209	1.0007917	1.000339	342.5486	293.22
31.82813658	0.09216854	293.36667	1.0007391	1.000317	342.5409	293.21
33.41954341	0.09681443	293.35228	1.00069	1.000296	342.5337	293.21
35.09052058	0.10169271	293.33885	1.0006442	1.000276	342.527	293.2
36.84504661	0.10681501	293.32631	1.0006014	1.000258	342.5207	293.2
38.68729894	0.11219353	293.3146	1.0005615	1.000241	342.5149	293.2
40.62166389	0.11784106	293.30366	1.0005242	1.000225	342.5094	293.19
42.65274708	0.12377107	293.29346	1.0004894	1.00021	342.5043	293.19
44.78538444	0.12999767	293.28393	1.0004569	1.000196	342.4995	293.19
47.02465366	0.13653569	293.27504	1.0004265	1.000183	342.4951	293.19
49.37588634	0.1434007	293.26673	1.0003982	1.000171	342.4909	293.18
51.84468066	0.15060905	293.25898	1.0003718	1.000159	342.487	293.18
54.43691469	0.15817791	293.25174	1.0003471	1.000149	342.4834	293.18
57.15876042	0.16612529	293.24499	1.000324	1.000139	342.48	293.18
60.01669845	0.17447012	293.23868	1.0003025	1.00013	342.4769	293.18
63.01753337	0.18323227	293.23279	1.0002824	1.000121	342.4739	293.17
66.16841004	0.19243261	293.22729	1.0002637	1.000113	342.4712	293.17
69.47683054	0.20209305	293.22216	1.0002461	1.000105	342.4686	293.17
72.95067206	0.21223658	293.21737	1.0002298	1.000098	342.4662	293.17
76.59820567	0.22288737	293.21289	1.0002145	1.000092	342.464	293.17
80.42811595	0.23407076	293.20872	1.0002003	1.000086	342.4619	293.17
84.44952175	0.2458134	293.20482	1.000187	1.00008	342.4599	293.17
88.67199784	0.25814324	293.20118	1.0001746	1.000075	342.4581	293.16
93.10559773	0.27108964	293.19778	1.000163	1.00007	342.4564	293.16
97.76087761	0.28468343	293.1946	1.0001522	1.000065	342.4548	293.16
102.6489215	0.29895697	293.19164	1.0001421	1.000061	342.4533	293.16
107.7813676	0.31394426	293.18888	1.0001326	1.000057	342.4519	293.16
113.1704359	0.32968098	293.1863	1.0001238	1.000053	342.4506	293.16
118.8289577	0.34620459	293.18389	1.0001156	1.00005	342.4494	293.16
124.7704056	0.36355444	293.18163	1.0001079	1.000046	342.4483	293.16
131.0089259	0.38177185	293.17953	1.0001007	1.000043	342.4473	293.16
137.5593722	0.40090019	293.17757	1.0000941	1.00004	342.4463	293.16
144.4373408	0.420985	293.17574	1.0000878	1.000038	342.4454	293.16
151.6592079	0.4420741	293.17403	1.000082	1.000035	342.4445	293.16
159.2421683	0.46421772	293.17244	1.0000765	1.000033	342.4437	293.16
167.2042767	0.48746858	293.17095	1.0000715	1.000031	342.443	293.16
175.5644905	0.51188202	293.16956	1.0000667	1.000029	342.4423	293.16
184.342715	0.5375162	293.16826	1.0000623	1.000027	342.4416	293.16
193.5598508	0.56443213	293.16704	1.0000581	1.000025	342.441	293.15
203.2378433	0.59269391	293.16591	1.0000543	1.000023	342.4404	293.15
213.3997355	0.62236883	293.16486	1.0000507	1.000022	342.4399	293.15
224.0697223	0.65352754	293.16387	1.0000473	1.00002	342.4394	293.15
235.2732084	0.68624424	293.16295	1.0000442	1.000019	342.439	293.15
247.0368688	0.72059682	293.16209	1.0000412	1.000018	342.4385	293.15
259.3887122	0.75666707	293.16129	1.0000385	1.000016	342.4381	293.15
272.3581478	0.79454087	293.16054	1.0000359	1.000015	342.4377	293.15
285.9760552	0.83430841	293.15984	1.0000336	1.000014	342.4374	293.15
300.274858	0.87606438	293.15918	1.0000313	1.000013	342.4371	293.15
315.2886009	0.91990818	293.15857	1.0000292	1.000013	342.4368	293.15
331.0530309	0.96594421	293.158	1.0000273	1.000012	342.4365	293.15
347.6056825	1.01428208	293.15747	1.0000255	1.000011	342.4362	293.15

364.9859666	1.06503689	293.15698	1.0000238	1.00001	342.436	293.15
383.2352649	1.11832948	293.15651	1.0000222	1.00001	342.4357	293.15
402.3970282	1.17428673	293.15608	1.0000207	1.000009	342.4355	293.15
422.5168796	1.23304188	293.15568	1.0000194	1.000008	342.4353	293.15
443.6427236	1.29473483	293.1553	1.0000181	1.000008	342.4351	293.15
465.8248598	1.35951246	293.15495	1.0000169	1.000007	342.435	293.15
489.1161027	1.42752901	293.15462	1.0000158	1.000007	342.4348	293.15
513.5719079	1.49894642	293.15431	1.0000147	1.000006	342.4346	293.15
539.2505033	1.57393473	293.15403	1.0000137	1.000006	342.4345	293.15
566.2130284	1.65267249	293.15376	1.0000128	1.000005	342.4344	293.15
594.5236799	1.73534717	293.15351	1.000012	1.000005	342.4342	293.15
624.2498638	1.82215562	293.15328	1.0000112	1.000005	342.4341	293.15
655.462357	1.91330452	293.15306	1.0000104	1.000004	342.434	293.15
688.2354749	2.0090109	293.15286	1.0000097	1.000004	342.4339	293.15
722.6472486	2.10950262	293.15267	1.0000091	1.000004	342.4338	293.15
758.7796111	2.21501896	293.15249	1.0000085	1.000004	342.4337	293.15
796.7185916	2.32581115	293.15232	1.0000079	1.000003	342.4336	293.15
836.5545212	2.44214297	293.15217	1.0000074	1.000003	342.4336	293.15
878.3822473	2.56429141	293.15203	1.0000069	1.000003	342.4335	293.15
922.3013596	2.69254731	293.15189	1.0000064	1.000003	342.4334	293.15
968.4164276	2.82721602	293.15177	1.000006	1.000003	342.4334	293.15
1016.837249	2.96861819	293.15165	1.0000056	1.000002	342.4333	293.15
1067.679111	3.1170905	293.15154	1.0000052	1.000002	342.4332	293.15
1121.063067	3.27298645	293.15144	1.0000049	1.000002	342.4332	293.15
1177.11622	3.43667722	293.15134	1.0000046	1.000002	342.4331	293.15
1235.972031	3.60855255	293.15125	1.0000043	1.000002	342.4331	293.15
1297.770633	3.78902167	293.15117	1.000004	1.000002	342.4331	293.15
1362.659165	3.97851428	293.15109	1.0000037	1.000002	342.433	293.15
1430.792123	4.17748153	293.15102	1.0000035	1.000001	342.433	293.15



What is the maximum distance you can expect to hear thunder from lightning 5 km high in calm conditions with average temperature 300 K, if the lapse rate (degs C / km) is:  
e. 7.5

Given:  $\Delta z = 5 \text{ km}$   
 $T = 300 \text{ K}$   
 $dT / dz = 7.5 \text{ degs C / km}$

Find: Maximum distance = ? km

Neglecting wind effects, we can use eq.14.64:

$$x_{\text{max}} = 2 * \sqrt{T * z / \text{lapse\_rate}}$$

$$x_{\text{max}} = 28.284271 \text{ km}$$

Check: Units ok. Physics ok.

N64e)

For a Rankine Combined Vortex model of a tornado, plot the pressure (kPa) and tangential wind speed (m/s) vs. radial distance (m) out to 125 m, for a tornado of core radius 25 m and core pressure deficit (kPa) of:  
e. 0.5

Assume density of air,  $\rho = 1 \text{ kg/m}^3$

Given: Core radius,  $R_0 = 25 \text{ m}$   
 Core pressure deficit,  $P$  at  $R_0 = 0.5 \text{ kPa} = 500 \text{ Pa}$

Find: Pressure = ? kPa  
 Tangential wind speed = ? m/s  
 Plot vs. radial distance out to 125 m

First, find  $M_{\text{tan\_max}}$  using eq. 14.70:

$$M_{\text{tan\_max}} = \sqrt{\Delta P_{\text{max}} / \rho}$$

$$M_{\text{tan\_max}} = 22.36068 \text{ m/s}$$

For,  $R < R_0$  (core region), use eq. 14.66 and 14.67:

$$M_{\text{tan}} = M_{\text{tan\_max}} * (R / R_0)$$

$$\Delta P = \Delta P_{\text{max}} * (1 - 0.5 * (R/R_0)^2)$$

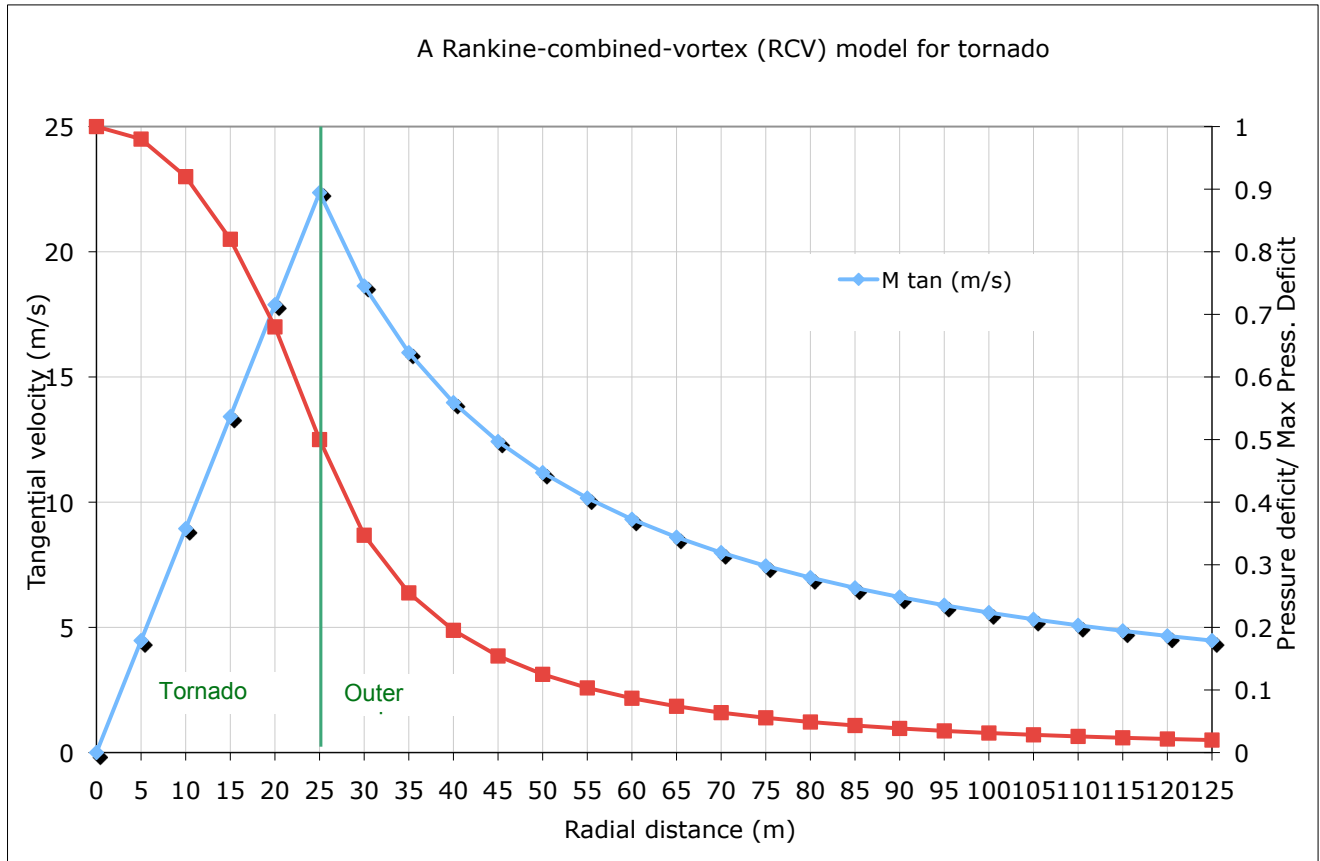
For  $R > R_0$  (outer region), use eq. 14.68 and 14.69:

$$M_{\text{tan}} = M_{\text{tan\_max}} * (R_0 / R)$$

$$\Delta P = \Delta P_{\text{max}} * 0.5 * (R_0/R)^2$$

Radial distance (m)	$M_{\text{tan}}$ (m/s)	$\Delta P$ (Pa)	$\Delta P / \Delta P_{\text{max}}$
0	0	500	1
5	4.47213595	490	0.98
10	8.94427191	460	0.92
15	13.4164079	410	0.82
20	17.8885438	340	0.68
25	22.3606798	250	0.5
30	18.6338998	173.61111	0.3472222
35	15.9719141	127.55102	0.255102
40	13.9754249	97.65625	0.1953125
45	12.4225999	77.160494	0.154321
50	11.1803399	62.5	0.125
55	10.1639454	51.652893	0.1033058
60	9.31694991	43.402778	0.0868056
65	8.60026145	36.982249	0.0739645

70	7.98595706	31.887755	0.0637755
75	7.45355992	27.777778	0.0555556
80	6.98771243	24.414063	0.0488281
85	6.57667052	21.626298	0.0432526
90	6.21129994	19.290123	0.0385802
95	5.88438941	17.313019	0.034626
100	5.59016994	15.625	0.03125
105	5.32397137	14.172336	0.0283447
110	5.08197268	12.913223	0.0258264
115	4.86101734	11.814745	0.0236295
120	4.65847495	10.850694	0.0217014
125	4.47213595	10	0.02



N66e)

What are the Fujita and Torro intensity indices for a tornado of max wind speed (m/s) of:  
e. 60

Given: Max wind speed = 60 m/s

Find: Fujita index = ?  
Torro intensity index = ?

Using eq.14.72,

$$M_{max} = a * (2 * F + 4) ^{1.5}$$

Then,  $F = 0.5 * ((M_{max} / a)^{(1/1.5)} - 4)$   
where a = 2.25 m/s  
F = 2.4628863

So, the tornado has a Fujita scale of F2 (Or using Table 14-7, has an Enhanced Fujita scale of EF2.)



**Using table 14-8, the tornado has a TORRO scale of T4.**

N70e)

**A mesocyclone at 38 degs N is in an environment where the vertical stretching ( $\Delta W / \Delta z$ ) is (20 m/s) / (2 km). Find the rate of vorticity spin-up due to stretching only, given an initial relative vorticity ( $s^{-1}$ ) of:  
e. 0.0010**

Given: Latitude = 38 degs N = 0.663225 rad  
 $\Delta W / \Delta z = 20 \text{ m/s per } 2 \text{ km} = 2000 \text{ m}$   
Initial relative vorticity = 0.001  $s^{-1}$

Find: Rate of vorticity spin-up due to stretching only = ?

Using eq. 14.77:

spin-up rate due to stretching =  $(\text{rel\_vort} + f_c) * dW/dz$   
where  $f_c = 2 * \omega * \sin(\phi)$   
 $f_c = 8.976E-05 \text{ s}^{-1}$

**So, spin-up rate = 1.090E-05  $s^{-1}$**

Check: Units ok. Physics Ok.

N73e)

**Given the hodograph of winds in Fig. 14.114a. Assume  $W = 0$  everywhere. Calculate the helicity H based on the wind-vectors for the following pairs of heights (km):  
e. 4, 5**

Assume:  $W = 0$  everywhere.

Given: Heights = 4 km and 5 km  
Hodograph in Fig. 14.114a.

Find: Helicity, H = ?

Use eq. 14.78, with  $W_{avg}$  and  $\Delta W = 0$

So,  $H = U_{avg} * (-\Delta V / \Delta z) + V_{avg} * (\Delta U / \Delta z)$

For the layer from 4 km to 5 km:

z (m)	U (m/s)	V (m/s)
4000	2.5	14.8
5000	13	15.2

$U_{avg} = 7.75$       ---  
 $V_{avg} = ---$       15

**H = 0.1544  $m / s^2$**

Check: Units Ok. Physics Ok.