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ELECTRICAL PROPERTIES OF AIR IN THE CARLSBAD CAVERNS

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ABSTRACT

Radon 222 and its daughter product concentrations in the Carlsba Caverns are higher than in outdoor air by a factor of several hundred. The effects of the radiation from these substances on the electrical properties of air in the Cave have been studied. The rate of ion-pair production, the ion density, and the electrical conductivity are much higher in the Cave than in outdoor air. The mobility of the ions is less than outdoors due to the high humidity and low condensation nuclei concentration. A small net space charge produces a barely detectable electric field of the order of one percent of the earth's fair weather field.

^{222}Rn and Daughter Product Activities

Air in unventilated caves is known to have radon and daughter product concentrations that are from 100 to 1000 times that of outdoor air as shown by Wilkening and Watkins (1976), Ahlstrand and Fry (1976), and Yarborough (1978). This enhancement in radioactivity occurs even though no more than background quantities of uranium and thorium minerals are present in the rock environment where the cave is located.

A brief comparison of the unique features of the radiation environment in the Carlsbad Caverns with that of the free atmosphere is shown in Table 1.

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Table 1. Comparison of ^{222}Rn and Daughter Product Activity in the Carlsbad Caverns with the Free Atmosphere

	Caverns			Outdoors
	Summer	Fall	Winter	
^{222}Rn (pCi/ℓ)	65±11	34±16	16±2	0.13±.06
Working Level (Yarborough - 1978)	0.32±.04	0.20±.09	0.13±.04	0.0006*

*Based upon measured ^{222}Rn and 50% equilibrium

^{222}Rn and daughter product levels peak in the summer months of June, July and August when outside temperatures rarely fall below the Cave temperature. Stable conditions exist under these conditions in which there is no exchange of outdoor air with that in the Cave. In the winter (January and February) outside air temperatures are usually lower than the Cave temperature causing the relatively ^{222}Rn-free outdoor air to mix with the warmer air in the Caverns, thus reducing ^{222}Rn concentrations. The fall figures represent a transition regime. The ^{222}Rn values shown are average values corrected to standard temperature and pressure for the seasons indicated from a total of 98 samples on missions to the Caverns from 1973 to 1978. The errors shown are standard deviations of the mean.

Working Levels for the Caverns given in Table 1 are from National Park Service data for 1975-1976 and 1977-1978 (Yarborough 1978). In both ^{222}Rn gas and Working Level cases summer Cave activity levels exceed that of outdoor air measured at the Visitor Center by factors of 500 and 530 respectively. The measured mean value of 0.13 pCi/ℓ for ^{222}Rn concentration in outdoor air is in agreement with that given by Junge (1963) for the free atmosphere over continents.

Ion Formation

During the radioactive decay of radon and its daughter products, alpha, beta, and gamma rays are given off. These radiations give up their energy by ionization and excitation of atoms and molecules which they encounter. A single alpha particle from the decay of ^{222}Rn will produce about 150,000 ion pairs with an average expenditure of 34 ev per pair. The complicated processes that are involved in the transformation of these ion pairs or those created by other ionizing agents into atmospheric small ions have been described by Mohnen (1977, 1979). Initially electrons and singly charged positive ions are formed from the air molecules with equal probability according to their abundance. In a very short time of the order of 1 μs the positive ions are transformed into primary small ions by charge transfer and ion-molecule reactions. The electrons attach to neutral molecules after reaching thermal energies. Both positive and negative ions undergo a series of reactions which may involve attachment, "switching", proton transfer or clustering processes. The only positive ions that are in equilibrium with the nitrogen, oxygen, water vapor and carbon dioxide in a clean atmosphere are the oxonium ion and its hydrates:

$$(H_3O)^+ \cdot (H_2O)_n$$

The degree of hydration (n value) depends upon temperature and humidity. The chief negative ions are:

$$O_2^- \cdot (H_2O)_n \text{ and } CO_4^- \cdot (H_2O)_n$$

The integral values of n again depend upon temperature and the ratio of water vapor to carbon dioxide concentrations.

In the real atmosphere a host of trace gases may be present which in concentrations from a few parts per million down to parts per trillion can lead to a wide variety of ion-molecule reactions. Since the lifetime of these small ions in the atmosphere is typically in the range from tens of seconds to tens of minutes, ion collisions with any trace gas are assured. Hence, chemical as well as electrostatic interactions are all possible.

It is clear from this brief review of the formation of atmospheric ions that any unique character of the air within the Carlsbad Caverns with respect to temperature, water vapor, carbon dioxide and other trace constituents can produce somewhat different ion characteristics, and as a consequence, the electrical parameters will be different from those found in the free atmosphere.

Some General Properties of Cave and Outdoor Air

Characteristics of the atmospheres in the Carlsbad Caverns and the free atmosphere are compared in Table 2. Temperature, water vapor (mixing ratio), carbon dioxide, and airborne particle content can all be factors in the formation processes, life-times, and mobilities of the ion population in the Cave.

Cave temperatures in the Main Caverns remain relatively constant the year around at about 14°C while summer minima outdoors seldom reach below about 17°C. On the other hand the average winter maximum temperature is approximately the same as the Cave temperature which means that conditions favorable for natural exchange of outdoor air with air in the Cave occurs most of the time during the winter season.

Table 2. A Comparison of Some General Properties of the Cave and Outdoor Air

	Caverns		Outdoors	
	Summer	Winter	Summer	Winter
Temperature (°C)				
Mean maximum	14±1[a]		32±2[b]	14±3[b]
Mean minimum			18±1[b]	-0.2±1.9[b]
Mixing Ratio (g/kg)	11±0.2		9.5[c]	3.0[c]
Carbon Dioxide (ppm)	450[a]	360[a]	330[a]	
Condensation Nuclei (x $10^9 m^3$)	1.5±1	2±1	40[d]	
Particulate Matter ($\mu g/m^3$)	6±4		20-100[e]	

[a]McLean 1971
[b]NOAA 1976-78
[c]WSMR 1969
[d]Wilkening 1977
[e]Pruppacher and Klett 1978

Ion cluster growth is directly affected by the availability of water vapor. The mixing ratio, defined as the number of grams of water vapor per kilogram of dry air, was calculated from wet and dry bulb temperatures in the Cave. A hygrothermograph provided continuous records of the relative humidity and temperature. Air in the Caverns contains almost 4 times as much water vapor as outdoor air during the winter months. The relative humidity in the Cave stays at about 90% while that for outdoor air in the area averages only about 45%.

Carbon dioxide which appears to influence the growth of negative atmospheric small ions is more abundant in the Cave than in the free atmosphere due to CO_2 released in the deposition of calcite from the Cave waters (McLean 1971).

Castleman and Tang (1977) point out that the growth of water molecules about ions cannot be expected to be of major importance where there is a high aerosol concentration. It is of interest, therefore, to examine the particulate content of the Cave atmosphere. This is done in terms of condensation nuclei counts based upon data from a General Electric Condensation Nuclei instrument and total airborne particulate determinations using a Staplex air sampler and a 10 cm diameter glass fiber filter. Condensation nuclei average concentrations were down by a factor of about 20 compared with data from the same instrument in a typical outdoor environment. Summer nuclei counts were marginally below winter averages in the Cave as expected due to increased air exchange. A few spot checks on gross particulate counts taken in the Cave were less by a significant amount compared with outdoor air. The particulate matter in outdoor air is known to vary over a wide range in going from remote rural areas to urban environments. The data of Table 2 clearly indicate that the Cave atmosphere is indeed a clean environment compared with the out-of-doors. This should favor the growth and retention of a large small-ion population within the Cave.

Atmospheric Electrical Parameters

The rate of ion-pair production in the Caverns is based upon a figure of 4.6 ion pairs $cm^{-3}s^{-1}$ generated by ^{222}Rn and ^{220}Rn and their daughters in outdoor air (Israel 1970). It is assumed that ionization is directly proportional to the ^{222}Rn concentrations in going from outdoor air to Cave air. Ion pairs are created in the Cave atmosphere in the summer at a rate of almost 200 times greater than in the free atmosphere based upon these assumptions and as shown in Table 3.

Positive and negative small ion concentration, the electrical conductivity, and ion mobilities were measured with a Gerdien conductivity meter similar to the one described by Chalmers (1967). A description of the instrument and an analysis of its operation are given in Jonassen and Wilkening (1965). The Cave values of conductivity and ion densities in the summer are approximately 100 and 800 times larger respectively than for the free atmosphere. This is to be expected from the ratio of the Cave-to-free-atmosphere concentrations of ^{222}Rn and its daughters.

The mobility of an ion is a measure of its drift velocity in a gaseous medium in response to an applied electric field. It is given in units of meters per second for each volt per meter of applied electric field. A high ion mobility implies a small ionic mass. Atmospheric small ions consist of molecular aggregates and have mobilities greater than $10^{-4} m^2/Vs$. Their radii will be less than $7 \times 10^{-10} m$ (Dolezalek 1979). Negative ions in the free atmosphere generally exhibit larger average mobilities than positive ions by 25 to 50 percent. As seen in Table 3 ions of both signs in the Cave exhibit lower mobilities than their outdoor counterparts. Further, there is no significant difference in mobility of the positive and negative ions. This result can be attributed to the high humidity and low aerosol particle concentration in the Cave which favors the growth of larger ions. It is suggested that the difference in the mobilities of positive ions in summer and fall may be related to a seasonal variation in the mixing of dry air from the surface with the Cave air.

Table 3. Atmospheric Electrical Parameters

	Caverns		Free Atmosphere	
	Summer	Fall	N.M. Tech	Literature
Ion Pair Production ($x10^6$ $m^{-3}s^{-1}$)	2300	1200	15	10[a]
Ion Density ($x10^8$)				
+ions/m^3	4000	500	5.4	5.0[b]
-ions/m^3	4000	500	4.4	5.0[b]
Conductivity ($x10^{-14}$)				
+$(ohm\text{-}m)^{-1}$	150	34	1.4	2.1[b]
-$(ohm\text{-}m)^{-1}$	150	33	1.4	2.1[b]
Mobility ($x10^{-4}$)				
+(m^2/Vs)	0.23	0.42	1.6	1.14[c]
-(m^2/Vs)	0.23	0.41	2.0	1.25[c]
Space Charge Density ($x10^6$ elem. charges/m^3)	--	-44	100	21[b]
Electric Field (V/m)	--	1.0	130	120[d]

[a]Israel 1970

[b]Pruppacher & Klett 1978

[c]Mohnen 1977

[d]Dolezalek 1979

It is of interest to investigate the possible existence of a residual electric field within the Cave due to a net space charge originating from a possible imbalance in positive and negative ion populations. Although the positive and negative ion density values given in Table 3 are the same for both summer and fall, the accuracy is less than 10%, and even a small difference could create a measurable field.

The Left Hand Tunnel in Carlsbad Caverns is suited for electrical field measurements because it is free of visitor traffic and machinery which could cause perturbations. The field was measured by an instrument modeled after the design of George Freier of the University of Minnesota and was supplied by C. B. Moore of the atmospheric electricity group at New Mexico Tech. The nature of this method is described by Israel (1974). Since the field in the Left Hand Tunnel can be expected to be small compared with the earth's fair weather field, it is close to the noise level of the instrument used and special precautions had to be taken.

The mean strength of the electrostatic field measured inside the Caverns is -1.2±.8 V/m. For comparison the earth's fair-weather field is approximately +120 V/m (Dolezalek 1979). The field in the cave is produced by an overall net negative space charge density of 7 x 10^{-12} coul/m^3 which is approximately 44 ions/cm^3; this compares to a net positive ion concentration of 100 ions/cm^3 in the free atmosphere as reported by Jonassen and Wilkening (1965) for fair weather conditions in the Socorro, New Mexico area. The negative sign of the field vector indicates that negative charge would drift toward the wall of the tunnel which is in agreement with a calculated net negative charge density. It is of interest to note here that while the net space charge in the free atmosphere is of the opposite sign and approximately twice as large as that in the Caverns, the total ion density of either sign in the fall season is 100 times greater in the Caverns than in the free atmosphere; clearly the net space charge density formation processes are different in these environments.

Summary

The relatively high summer ^{222}Rn concentration of 65 pCi/ℓ in the Carlsbad Caverns results in an ion-pair production rate that is about 200 times that which occurs in the outdoor air. Characteristic values of conductivity during the summer months when radon concentrations are greatest are 150 x 10^{-14} (ohm-m)$^{-1}$ which exceed those of the free atmosphere by approximately a factor of 100. Ion densities, both positive and negative, within the Cave are about 800 times those of outdoor air during the summer months at about 4000 x 10^8 ions/m^3. On the other hand, the mobilities of both positive and negative small ions in the Cave are smaller than their counterparts in the out-of-doors. The chief factor in this difference appears to be the high humidity inside the Cave which combined with the low aerosol content contributes to the ready growth of ion complexes. Average mobilities for the total ion population were found to vary from 0.23 x $10^{-4}m^2 V^{-1}s^{-1}$ in the summer to 0.42 x $10^{-4}m^2V^{-1}s^{-1}$ in the fall. A weak electric field was detected which results from a small excess of negative ions in the cave environment.

The results of this study have provided new information on the atmospheric electrical environment of the Carlsbad Caverns. In addition questions regarding the basic scientific nature of atmospheric ions have been addressed. Although the normal atmospheric electric parameters found in the Carlsbad Caverns vary widely from those of outdoor air, there appears to be no reason to expect either adverse or beneficial effects on living organisms at the levels encountered.

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REFERENCES CITED

Ahlstrand, G.M., and P.L. Fry. 1976. Alpha radiation monitoring at Carlsbad Caverns. Pages 691-693 in R.M. Linn, ed. First Conference on Scientific Research in the National Parks. National Park Service Transactions and Proceedings Series No. 5, 1979.

Castleman, H.W., and I.N. Tang. 1977. On the molecular properties of atmospheric ion clusters and their relationship to nucleation. Pages 24-29 in H. Dolezalek and R. Reiter, eds. Electrical Processes in Atmospheres, Steinkopff. Darmstadt.

Chalmers, J.A. 1967. Atmospheric Electricity, Second Edition, Pergamon Press. London.

Dolezalek, H. 1979. Atmospheric Electricity. Pages F212-213 in R.C. Weast, ed. Handbook of Physics and Chemistry, 60th Ed. CRC Press. Boca Raton, Fla.

Israel, H. 1970. Atmospheric Electricity, Vol. I. Israel Program for Scientific Translations. Jerusalem.

____. 1974. Atmospheric Electricity, Vol. II. Israel Program for Scientific Translations. Jerusalem.

Jonassen, N., and M.H. Wilkening. 1965. Conductivity and concentration of small ions in the lower atmosphere. J. Geophys. Res. 70:4.

Junge, C.E. 1963. Air Chemistry and Radioactivity. Academic Press. New York.

McLean, J.S. 1971. The microclimate in Carlsbad Caverns, New Mexico. Open file report, U. S. Department of the Interior, Geological Survey, Albuquerque, N.M.

Mohnen, V.A. 1977. Formation, nature, and mobility of ions of atmospheric importance. Pages 1-17 in H. Dolezalek and R. Reiter, eds. Electrical Processes in Atmospheres. Steinkopff. Darmstadt.

____. 1979. Nature of ions in unpolluted air. Page F207 in R.C. Weast, ed. Handbook of Physics and Chemistry, 60th Ed. CRC Press. Boca Raton, Fla.

National Oceanic and Atmospheric Administration (NOAA). 1976-1978. Climatological Data - New Mexico. National Climatic Center. Asheville, N.C.

Pruppacher, H.R., and J.D. Klett. 1978. Microphysics of Clouds and Precipitation. Reidel. Boston.

White Sands Missile Range (WSMR), Atmosphere Sciences Office. 1969. White Sands Desert Site. WSMR Climatography No. 14 (DR-397).

Wilkening, M.H. 1977. Influence of the electric fields of thunderstorms on radon daughter ion concentrations. H. Dolezalek and R. Reiter, eds. in Electrical Processes in the Atmosphere. Steinkopff. Darmstadt.

_____, and D.E. Watkins. 1976. Air exchange and ^{222}Rn concentration in the Carlsbad Caverns. Health Physics 31:139-145.

Yarborough, K.A. 1978. Investigations of radon and thoron produced radiation in Natural Park Service caves. Conference on The Natural Radiation Environment III, April 23-28, 1978. Houston, Texas. In press.