Ice is a mineral that exhibits paraelectricity, piezoelectricity and pyroelectricity [1,2]. Exploring whether the electrical properties of ice may influence the formation of proto-metabolic chemical systems on its surface in various settings is the aim of this work. Background information on relevant topics will be presented so that participants will be familiar with paraelectricity, piezoelectricity, pyroelectricity, ferroelectricity, capacitance [3]. The amount of electrical energy available will be quantified and the parameters of various terrestrial, planetary and cometary settings will be introduced. The action of deformation mechanisms on ice (and other rock) may also produce electrical changes. The action of these and other features will be addressed, with an aim of describing how these may provide electrical energy to a chemical system. Chiral enrichment of surficial molecules will also be explored.

Keywords
origin of life, origin of metabolism, ice, piezoelectric, pyroelectric, ferroelectric, chemical battery, proton pump.

Is Ice a Mineral?

Ice is naturally occurring, abiogenic, representable by a chemical formula (H2O) and has an ordered atomic structure. (Hexagonal system - Dihexagonal Dipyramidal class - 6/mmm). Though it is not solid at room temperature, it is solid at ambient temperatures on the Earth, and this may be the source of some of the equivocation about its status as a mineral. In many planetary environments ice will exist as a solid, this phenomenon is called ambient electrification, or the pyroelectric effect [9].

What might some general benefits be to pre-biarch chemistry existing on mineral faces?

For the creation of homochirality in situ, it is important to look for causes that are extant and plausible. Crystalline materials that rotate photons as they are transmitted are optically active, and many minerals fall into this class. Structurally, there are left- and right-handed varieties of many minerals - defined by their optical activity - and many of these can serve as templates for chiral enrichment via adhesion to the face. Hazen [4] includes most common rock-forming minerals in this category: e.g. quartz, alkali feldspars, clinoxyrocine, and calcite. These fall into two classes: (1) minerals whose lattice is chiral (or whose lattice exhibit anisotropic electrical phenomena such as ferro- or paraelectricity), and (2) minerals whose surface expression lacks a mirror inversion plane. Into the first group fall many common minerals and mineral families: alunite, apatite, beryl, cancrinite, epsomite, galena, ice, nepheline, prehnite, pyroclore, quartz, rutile, serpentine, sodalite, sphaibrite, topaz, tourmlaine and zoelite [3]. Of these, a few are of particular interest in a geologic setting that might be significant to the origin of life:

- Zeolites are porous minerals and are significant because they occur in mid-ocean ridge environments, where the chemical gardens hypothesis of Barge et al. [5] and others is favored.
- Galena is a sulfide mineral and can be abundant in that environment as well as other geothermal fields.
- Apatite and serpentine are secondary (alteration) minerals and are significant if the origin of life occurs in weathered environments.

What are piezolectric materials?

The piezoelectric effect (electric field or charge caused by applied pressure) is a crystal lattice effect, as deformation from stress or strain displaces the positions of shared electrical bonds [6,7,8]. In general, if a lattice is symmetrical about its center, any electrical charge caused by a change in shape will be offset by an orthogonal charge of opposite sign, and these cancel. Crystal lattices that are not centro symmetric are piezoelectric. Typical magnitudes are on the order of 10⁻¹⁴ coulombs per newton for single crystal samples.

What are pyroelectric materials?

Water is a polar molecule. Any material whose structure has an axis with dissimilar ends, and whose ends are of uneven electric charge is a polar material. In polar minerals, electric charges located at the ends of the permanent electric dipole are rapidly neutralized by the environment under normal conditions. During heating or cooling, however, the charges do not have time to dissipate, and are detected as a phenomenon called pyroelectricity, or the pyroelectric effect [9]. It is sensitive to both the change in temperature and the rate of change in temperature of a polar material. Tourmalines are common minerals that exhibit this effect [10]. Typical magnitudes are on the order of 10⁻⁹ coulombs per square meter per Kelvin for single crystal samples.

What are dielectric materials?

Capacitance is the ability to store charge, and is synonymous with the dielectric strength of materials. Capacitance occurs by the rearrangement of electric dipoles in two settings: first, from polar molecules whose net electric dipole moment is constant (i.e. in a polar material), and from polar molecules whose net electric dipole moment is constant (i.e. in a polar material) [11]. Polarization itself may be caused by one of four mechanisms [12]:

1. Electronic polarization is caused by the displacement of electrons.
2. Ionic polarization is caused by the displacement of atoms or ions.
3. Electric dipole polarization is caused by coherent orientations of polar molecules.
4. Space-charge polarization is caused by migration of charged particles through a substance.

The amount of time it takes to store or release electric charge depends on the mechanism involved, in order of increasing charge time: electronic, ionic, electric dipole or space-charge. The dielectric permittivity of minerals varies over about two orders of magnitude, from about three (for several minerals) to 173 (for rutile) [11]. Permittivity values for rocks range from three to about 20 [11].

Some materials may exhibit piezoelectricity. If the effect is reversible (so that the sign of the polarization can be switched by applying a larger electric field of opposite sign), then the material is termed ferroelectric. The name ferroelectric is akin to ferromagnetic, not for its reference to iron, but in signifying reversibility. The ferroelectric effect is due to the presence of two competing sublattice orientations in the crystal. A sublattice is a part of the crystal lattice, which, when taken separately, may have a different symmetry from the overall lattice. The applied field allows the sublattices to reorient, favoring one of these two [13]. Ice is a common ferroelectric mineral at low temperatures [14]. The competing crystal sublattices are responsible for ice being lighter than water and for other anomalies. A ferroelectric crystal need not have an asymmetric unit cell to express piezoelectricity; the sublattices provide the asymmetry. All ferroelectric, antiferroelectric, or paraelectric minerals exhibit pyroelectricity and piezoelectricity, and all pyroelectric minerals are piezoelectric.

What are ferroelectric and paraelectric materials?

If two competing crystal sublattice orientations are at right angles to each other, then the material is called antiferroelectric, and generally polarizes more strongly in one direction than the other. If an external electric field polarizes a mineral, but is unable to switch its polarity, and interacts with the mineral in such a way that the applied field then causes extra polarization (an increase that is more than linear), the material is termed paraelectric. At ambient temperatures on Earth ice is a paraelectric mineral. Its presence influences the strength of an electric field.

Where does ice fit in with ferroelectrics in its phase diagram?

<table>
<thead>
<tr>
<th>Phase</th>
<th>Temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tc</td>
<td>273 K</td>
</tr>
<tr>
<td>Tₚ</td>
<td>173 K</td>
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</tbody>
</table>

How much electrical influence would be present in ice?

Piezoelectric (Electric Charge) Strain (d) for ice: dₜ = 2 x 10⁻¹² C N⁻¹ [15]

The calculated strain is given by the following equation: d = dₑ - dₛ, where dₑ is the strain caused by the electric field in Voigt notation. The location of electricity is shown by the first number, and strain by the second. It indicates that electricity was expressed along the z axis when compressive strain was applied along the z axis.

Can ice act as a chemical battery?

Recent experiments by the author suggest that there may be viable conditions for power production in cold-weather locations from solar panels made out of ice. The most promising model uses a three-layer panel, with a partially melted layer of ice plus acid (or base) sandwiched between two layers of ice.

"I have been meaning to drop you a note about panels. There was a cold snap that allowed a second trial. It was unexpectedly prolonged, which caught me off guard and unable to pull together a third trial but I did do some long term testing of the panels (\"Trial #1\" from your original schedule). Interesting results that I will find a time to write up. Essentially the HCl seems to have mixed more completely with the distilled water (as compared to vinegar and bleach), such that the freezing point was not sufficiently depressed to maintain a slush layer at the colder end through use. That said there was current flow, in fact the voltage generated did not diminish appreciably with time. This may be because the panels showed good physical endurance. I ran them for about a week. There may have been some minor indication of a solar effect but for sure we made ice batteries. Under a 1K ohm load they pumped out about 0.3 – 0.4 V non-stop, night and day." (M. Retallack, March 23, 2017)

What does all of this say in relation to an origin of metabolism?

Three features are especially notable in the above treatment: (1) Ice can form batteries and proton pumps. (2) Ice can supply electricity from stress and strain. (3) During phase transitions ice can release electrical energy. (4) Ice can create non-linear responses to ambient electric fields. Thus, ice ought to be seen as a potential locus of the origin of metabolic processes. Note that the chemistries of various terrestrial, planetary and cometary settings are distinct. A target of study might be to look for natural interlayering of ice and other materials to see whether chemical cycling can be found. To the author’s knowledge this has not been carried out yet. Terrestrial environments might be studied in this fashion preliminary to investigations on other solar system objects, such as Europa or Triton. Surface effects from day-night cycling might be associated with measurable proto-metabolism in both biological and geological systems. Around the Sun and comets may play a significant role in the chemical evolution and not just delivery of organics. A strong interest may be to examine environments rich in water ice and carbon species to explore chemical reaction systems.