Other energy sources

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***Abstracts:** In this article have been concerned with renewable energy flows and stores based on solar radiation, gravitation between celestial bodies, the mechanical energy involved in atmospheric and oceanic circulation, as well as a number of (sensible or latent) heat sources, the origin of which were solar or geological. It is believed that the most important such sources have been listed, but there could among those omitted be some that still have a certain amount of significance.*

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INTRODUCTION

In this article of heat sources, in particulat, the list is far from complete, considering that any difference in temperature constitutes a potential source of energy. It may not be practical to attempt to extract energy from the difference in air or soil temperature between the artic and equatorial regions, but the corresponding difference in water temperature is , in fact, the basis for the corresponding difference in water temperature is, in fact, the basis for the temperature gradients in some oceanic regions, owing to the water transport by currents. One case in wich a stable temperature difference might be usable in ways similar to those proposed for ocean temperature gradients is offered by the difference between the artic air temperature and the water temperature at the base of the ice sheets covering artic oceans. The average air temperature is about -25^0C for the period Ocomber-March, but the temperature at the ice-water interface is necessarily close to 0^0C.

It is natural to ask whether other energy forms present in the regime of the Earth, such as electromagnetic, earthquake, chemical or nuclear energy, can be considered as energy resources and to what extent they are renewable. The rest of this article will briefly deal with examples of such energy forms.

ATMOSPHERIC ELECTRICITY

The Earth is surrounded by a magnetic field, and form a height of about 80 km a substantial fraction of atmospheric gases is in an ionised state. It is thus clear that electromagnetic forces play an important role in the upper atmosphere. Manifestations of electromagnetic energy in the lower parts of the atmosphere are well known in the form of lightning. Speculations on the possibility of extracting some of the electrical energy contained in a thunderstorm have appeared. An estimation of the amounts of energy involved requires knowledge of the electrical propriets of the atmosphere.

In figura 1, calculated values of the electrical conductivity of the atmosphere are shown as a function of height for the lowest 200 km. It is shown that the conductivity is low in the troposphere, increases throught the stratosphere and increases very sharply upon entering the ionosphere. Strong horizontal current systems are found in the region of high conductivity at a height of around 100 km (the dynamo currents). Vertical currents directed towards the ground are 6-7 orders of magnitude smaller for situations of fair weather, averaging about 10^{-12} A m^{-2} in the troposphere. Winds may play a role in generating the horizontal currents, but the energy input for the strong dynamo currents observed at mid-latitudes is believed to derive mainly from absorbtion of ultraviolet solar radiation by ozone.
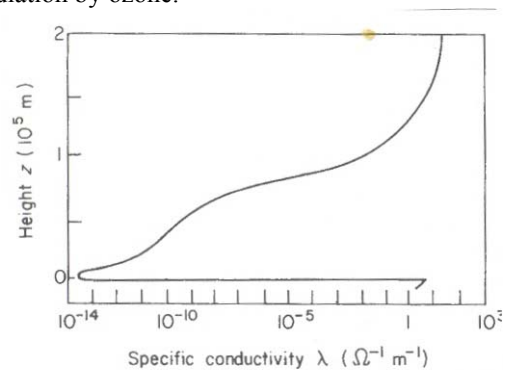

Figura 1. Electric conductivity of the atmosphere at noon on a clear day as a function of height, a substantial night-time reduction in λ takes place

The fair weather downward current of 10-12 A m-2 builds up a negative charge on the surface of the Earth, the total value of which on average is around 10^5 C. Locally, in the thunderstorm regions, the current is reversed and much more intense. Together these currents constitute a closed circuit, the flow through which is 500-100 A, but in such a way that the downward path is dispersed over most

of the atmosphere, while the return current in the form of lightning is concentrated in a few regions (apart from being intermittent, causing time variations in the charge at the Eart`s surface). The power P associated with the downward current may be found from

$$P = \int I^2 \lambda^{-1} dz, \tag{1}$$

Where I ($\approx 10^{-12}$ A m^{-2}) is the average current and $\lambda(z)$ is the conductivity function, or more simply from

$$P = IV = {IQ}/{C}, \tag{2}$$

Where C is the capacitance of the Earth relative to infinity (V the corresponding potential difference) and Q ($\approx 10^5$ C) is its charge. The capacitance of a sphere with the Earth`s radius $r_s$(6.4 $\times$ 10$^6$ m) is C= $4\pi\varepsilon_{0n}r_s$ = 7 $\times$ 10$^{-4}$ F ($\varepsilon_0$ being the dielectric constant for vacuum), and thus the average power becomes P$\approx$6 $\times$ 10$^{-5}$ W m$^{-2}$. The energy stored in the charge Q of the Earth`s surface, relative to a situation in wich the charges were all moved to infinity, is

$$W_{\infty}^{electric} = {1}/{2} \, {Q^2}/{C} \approx 3 \times 10^{42}. \tag{3}$$

In practice, the charges could only be moved up to the ionosphere (potential difference less than 10^6 V), reducing the value of the stored energy by almost two orders of magnitude. In any case, the charge of the Earth, as well as the trophospheric current system, constitutes energy sources of very small magnitude, even if the more concentrated return flux of lightning could be utilised (multiplying the average power estimate by the area of the earth, one obtains a total power of 3 $\times$ 10^{10} W).

SALINITY DIFFERENCES

Useful chemical energy may be defined as energy that can be released through exotermic chemical reactions. In general, chemical eergy is associated with chemical bindings of electrons, atoms and molecules. The bindings may involve overlapping electron wavefunctions of two or more atoms, attraction between ionised atoms or molecules, and long-range electromagnetic fields created by the motion of charged particles (notably electrons). In all cases, the physical interaction involved is the Coulomb force.

The organisation of atoms or molecules in regular lattice structures represents another manifestation of chemical bindings. Some substances possess different crystalline forms, which may exist under given external conditions. In addition to the possibility of different solid phases, phase changes associated with transitions among solid, liquid and gas phases all represent different levels of latent energy.

Solutions represent another form of chemical energy, relative to the pure solvent. The free energy of a substance with components $i = 1$, 2,..., there being n_i mol of the ith component, may be written

$$G = \sum_i n_i \mu_i, \tag{4}$$

where μ_i is called the chemical potential of component i. For a solution, μ_i can be expressed in the form

$$\mu_i = \mu_i^0 + RT \log(f_i x_i), \tag{5}$$

where R is the gas constant (8.3 J K^{-1} mol^{-1}), T is the temperature (K) and $x_i = {n_i}/{(\sum_j n_j)}$ the mole fraction. μ_i^0 is the chemical potential that would correspond to $x_i = 1$at the given pressure P and temperature T, and f_i is the activity coeficient, an empirical constant wich approaches unity for ideal solutions, an example of which is the solven of a very dilute solution (whereas, in general, f_i cannot be expected to approach unity for the dissolved component of a dilute solution).

It follows from (4) and (5) that a solution represents a lower chemical energy than the pure solvent. The most common solution present in large amounts on the Earth is saline ocean water. Relative to this, pure or fresh water such as river run-off represent an elevated energy level.

Taking the average ocean salinity as about 33 $\times$ 10^{-3} (mass fraction), and regarding this entirely as ionised NaCl, $n_{Na^+} = n_{Cl^-}$ becomes about 0.56 $\times$ 10^3 mol and

$$\mu - \mu^0 =$$
$$RT \log x_{water} \approx -2RT \, n_{water} \, {n_{Na^+}}/{n_{water}} \tag{6}$$

Consider now a membrane which is permeable for pure water but impermeable for salt as indicated in Figure 2. On one side of the membrane, there is pure (fresh) water, on the other side saline (ocean) water.
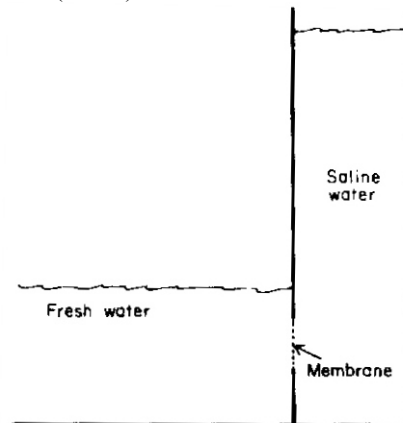

Figure 2. Schematic picture of an osmotic pump

Fresh water will flow through the membrane, trying to equalise the chemical potentials μ_0 and μ initially prevailing on each side. If the ocean can be considered as infinite and being rapidly mixed, then n_{Na^+} will remain fixed, also in the vicinity of the membrane. In this case each m^3

of freshwater penetrating the membrane and becoming mixed will release an amount of energy, which from (4) is

$$\delta G = \sum_i (n_i \delta\mu_i + \mu_i \delta n_i) \approx n_{water}(\mu^0 - \mu) \approx 2RTn_{Na^+}.$$

(7)

For a temperature T ≈ 285 K (considered fixed), $\delta G \approx 2.65 \times 10^6 J$. The power corresponding to a fresh-water flow of 1 m³ s⁻¹ is thus $2.65 \times 10^6 W$. The world-wide run-off of about $4 \times 10^{13} m^3 y^{-1}$ would thus correspond to an average power af around $3 \times 10^{12} W$.

The arrangement schematically shown in Figure 1 is called an osmotic pump. The flow of pure water into the tube will idealy raise the water level in the tube, until the pressure of the water head balances the force derived from the difference in chemical energy. The magnitude of this osmotic pressure P^{osm}, relative to the atmospheric pressure P_o on the fresh water surface, is found from the thermodynamic relation

$$VdP - SdT = \sum_i n_i d\mu_i,$$

(8)

where V is the volume, S is the entropy and T is the temperature. Assuming that the process will not change the temperature (considering the ocean a large reservoir of fixed temperature) insertion of (8) yields

$$P^{osm} = \delta P \approx n_{water}V^{-1}\delta\mu_{water} \approx 2RTn_{Na^+}V^{-1}$$

(9)

Inserting the numerical values of the example above, $P^{osm} = 2.65 \times 10^6 N\ m^{-2}$, corresponding to a water-head some 250 m above the fresh water surface. If the assumption of fixed mole fraction of salt in the tube is to be realised, it would presumably be necessary to pump saline water into the tube. The energy spent for pumping, however, wolud be mostly recorverable, since it also adds to the height of the water-head, which may be used to generate electricity as in hydropower plant.

An alternative way of releasing the free energy difference between solutions and pure solvents is possible when the dissolved substance is ionised (the solution is then called electrolytic).

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