A note on the loss of hydrogen and the supply of hydrogen to the Earth as a direct or indirect effect of the solar wind

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Summary. — The rate at which hydrogen is supplied to the Earth by the solar wind, and the rate at which hydrogen escapes from the Earth by diffusion into space are compared on the basis of recent estimates. It is found that the hydrogen supplied by the solar wind is roughly comparable to or may even be larger than present hydrogen losses. The Earth may have lost most of its hydrogen at an early stage when, according to Urey and Miller (1959), Fox (1960) and others, the Earth had a reducing, instead of an oxidizing atmosphere. However, no sufficient evidence is yet available to determine whether the Earth is still losing more hydrogen than it receives. The common notion that the Earth is still in the process of losing its hydrogen is therefore in question.

Riassunto. — Sulla base di recenti stime, si confronta il tasso di idrogeno fornito alla Terra dai venti solari in rapporto al tasso di fuga dell'idrogeno dalla Terra in seguito a diffusione nello spazio. Si constata che l'idrogeno fornito dai venti solari è pressoché pari, forse anzi superiore a quelle che sono le perdite attuali di idrogeno. È da presumere che la Terra abbia perso la maggior parte del proprio idrogeno in uno stadio primario, quando — secondo Urey e Miller (1959), Fox (1960) ed altri — l'atmosfera della Terra era del tipo riducente, invece che ossidante. Comunque, non sono state finora portate prove concludenti per determinare se, tuttora, la Terra continui a perdere idrogeno in quantità superiore a quella che riceve. L'ipotesi generalmente accettata, secondo cui il processo di riduzione del contenuto di idrogeno della Terra sarebbe tuttora in corso, è quindi posta in dubbio.

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1. – Introduction.

After the discovery of the substantial intensity of the stream of protons and hydrogen atoms carried by the solar wind, the question has arisen whether the rate at which hydrogen is supplied to the Earth by the solar wind might be comparable to or larger than the rate at which the Earth is losing hydrogen by diffusion into space. Only very rough estimates of the time rates are possible at present, and the main purpose of this note is to attract attention to the problems involved and their possible implications rather then bring a final solution.

2. – Estimate of Hydrogen Supplied by Solar Wind.

Only a high estimate of the rate of hydrogen supplied to the Earth by the solar wind — obtained by disregarding the affect of the Earth's magnetic field on charged particles — seems meaningful on the basis of present information.

According to Jokipii [1], the flux of the solar wind is approximately 3×10^8 protons/cm².sec in the vicinity of the Earth. Other recent estimates (Brigde, ([2]() differ from this by a factor 3 either way. Using the first estimate, the amount of hydrogen from the solar wind which would be intercepted by the Earth if the Earth did not have a magnetic field or if the solar wind contained a comparable amount of uncharged particles would be:

$$\left(3 \times 10^8 \frac{\text{protons}}{\text{cm}^2 \cdot \text{sec}}\right)\left(\frac{1}{6.02 \times 10^{23} \dfrac{\text{protons}}{\text{mole of } H}}\right)\left(\frac{\text{gm}}{\text{mole of } H}\right)\left(\frac{3.6 \times 10^3 \text{ sec}}{\text{hr}}\right)$$

$$\left(8760 \frac{\text{hr}}{\text{yr}}\right) \pi R^2 = \left(1.57 \times 10^{-8} \frac{\text{gm}}{\text{cm}^2 \cdot \text{yr}}\right) \pi R^2 .$$

(where R is the radius of the Earth).

Because of the Earth's magnetic field and the effect of the magnetosphere on charged particles, the actual amount of solar-wind-hydrogen which would reach the Earth's atmosphere would be only a fraction of this figure which should therefore be considered as a high estimate. Present theories and available information give discrepant estimates of this fraction and it has not been decided whether this fraction would be substantial or not.

3. – Estimate of hydrogen loss from Earth.

According to Spitzer ([3]), (table 5, page 245) the time of escape of free hydrogen from the Earth is 3.5×10^4 years, assuming an upper atmosphere temperature of 1000°K. According to Farley et al. ([4]) the approximate temperature from 350 to 500 km is 1000°K; according to Evans ([5]) the ion-temperature at about 400 km is approximately 900°K. The time of escape is defined as the time in which the amount of hydrogen lost by the Earth would be equal to the amount of hydrogen in its atmosphere on the assumption that the hydrogen concentration in the atmosphere were maintained constant by a continuous supply.

The amount of hydrogen in the atmosphere per cm² of the Earth's surface is $3.5 \times 10^{-5} \frac{\text{gm}}{\text{cm}^2}$ (Hutchinson, ([6])). Hence the rate of hydrogen loss from the atmosphere is estimated to be:

$$\left(3.5 \times 10^{-5} \frac{\text{gm}}{\text{cm}^2}\right)\left(\frac{1}{3.6 \times 10^4 \text{ yrs}}\right)(4\,\pi R^2) =$$

$$= \left(3.9 \times 10^{-9} \frac{\text{gm}}{\text{cm}^2 \cdot \text{yr}}\right) \pi R^2 .$$

(where R is the radius of the Earth).

Comparing this with the high estimate given in part 2 of the hydrogen accumulation shows that the rate of hydrogen gain could be as large as or even larger than the rate of hydrogen loss. Recent work by Chamberlain and Campbell ([7]) indicates that the rate of hydrogen loss from the atmosphere may be slightly smaller then the value calculated above.

4. – Conclusion.

In spite of the considerable uncertenity both in the hydrogen loss and the hydrogen supply by the solar wind, the least one can say about the result is that: *One cannot take it for granted that the Earth's present* *hydrogen balance is negative*, or in other words that the Earth is still losing more hydrogen than is supplied to it by the solar wind.

This conclusion does not contradict the explanation commonly given to the fact that the Earth as well as the other three terrestrial planets (namely Mars, Venus and Mercury) have a low content of hydrogen compared with the larger outer planets and the cosmic abundance of this element. The explanation that the Earth's gravitational field is incapable of retaining a large concentration of hydrogen in its atmosphere remains valid. However, the main loss of hydrogen by the Earth must have occurred at the time when the Earth had a reducing instead of an oxydizing atmosphere and probably contained a substantial concentration of hydrogen in its atmosphere (Urey and Miller ([8]), Fox ([9])).

The transformation from reducing to oxydizing atmosphere caused by photosynthesis in living systems may have influenced the Earth's hydrogen balance in two different ways:

1 – By binding most atmospheric hydrogen into water, thus preventing it from reaching the upper regions of the atmosphere where it could be lost by diffusion into space.

2 – By supplying a chemical reagent capable of binding a significant portion of the hydrogen carried to the Earth by the solar wind.

Whether at present the net result of these phenomena is still a reduction or a tight balance or even an increase of the Earth's hydrogen is an unresolved question. However the very fact that the two figures are so close to one another that there can be any doubt at all about this point suggests an even balance between hydrogen supplied by the solar wind and hydrogen lost from the Earth. Otherwise one would have expected to find a difference by several orders of magnitude between the two figures, and the facts presented here would be difficult to explain as pure coincidence.

The Earth may be losing approximately the same amount of hydrogen which is being supplied to it by the solar wind, and the concentration of hydrogen, and perhaps even the concentration of water vapor in the upper stratosphere may basically depend on this hydrogen balance.

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