IS NUCLEAR FUSION WORTH THE WAIT? THE GREENHOUSE AS A RED HERRING

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Abstract – Nuclear fusion seems unviable in view of the invalidity of the familiar nuclear binding energy curve (as previously argued at length). Unsurprisingly, therefore, clear-cut cases of nuclear fusion are practically non-existent (at least in the public domain). Recent reports, intriguingly, indicate renewed interest in nuclear fusion by both public and private agencies. As the fundamental basis of fusion seems dubious, perhaps a more circumspect approach – in view of the enormous investments involved – is indicated. Furthermore, fusion is being seen as an attractive alternative to fossil fuels, which are associated with greenhouse gas emissions. However, there are apparently serious problems with the current view of global warming, in particular the neglect of atmospheric heating *via* Raman scattering of visible light by N_2 and O_2, as also the possibility that the greenhouse gases emit infrared radiation 'spontaneously' *via* thermal excitation. These considerations indicate a fundamental reappraisal of current approaches to global warming and the search for alternative energies.

INTRODUCTION

Nuclear Fusion

Dalton's theory and Prout's Law

Dalton's atomic theory of matter (1803) found a precise and quantitative expression in Prout's Law (1815) [1]. Whereas the question of atomic weights was a natural consequence of Dalton's theory, prudence clearly indicated the need for a relative scale of the atomic weights – with respect to hydrogen (the lightest element) by convention. Prout's law then required that each atomic weight be an integral multiple of that of hydrogen, indicating the prevailing belief that the hydrogen atom was the building block for the atoms of the heavier elements.

In the intervening century leading up to the Bohr-Rutherford model of the atom, deviations from Prout's Law were apparently explained as arising from experimental errors. With the coming of age of modern nuclear physics and chemistry, however, the abandonment of

Prout's Law was deemed fundamentally necessary for at least two reasons. In particular, the variable isotopic composition of the majority of the elements meant that the atomic weight of an element depended on the location of its natural occurrence.

However, this caveat applied only to the 'gross' atomic weight of the element. Intriguingly, it was proposed that the atomic *mass* of each isotopic constituent was subject to a more subtle and fundamental deviation from Prout's Law (as extended to the individual isotopes).

Early mass spectrographs: the 'mass defect' and the nuclear binding energy curve

The above 'mass defects' – purportedly discerned from early mass spectrographic measurements and according with Einstein's theory of mass-energy equivalence – apparently arose from the loss of mass associated with the formation of every atom from its sub-atomic constituents at the time of its creation in the early universe. (It is implied that the large binding energies involved manifest as measurable mass changes.)

The mass spectrographic studies apparently led to an estimate of the nuclear binding energy of each elemental atomic isotope from the mass defect. This led to the familiar nuclear binding energy curve, which remains the fundamental basis of the theory of nuclear structure. Thus, essentially, it is believed that the nuclear binding energy (per nucleon) steadily increases with atomic mass for the lighter elements up to ^{56}Fe, thence decreasing gently in approaching the trans-uranides.

The nuclear binding energy curve apparently explains the radioactivity of the uranides and other heavy elements. This, of course, is the basis of nuclear fission energy, and thus apparently represents a triumph of current nuclear theory. Intriguingly, furthermore, the nuclear binding energy curve also indicates the possibility of nuclear fusion (among the lighter elements), as the heavier elements in the series are deemed to be more stable by virtue of a greater mass defect.

The case for nuclear fusion

However, although nuclear fission is well established, nuclear fusion apparently remains controversial and unproven in its potential for large scale civilian applications. Indeed, as has been previously argued at considerable length [1], the very concept of nuclear binding energy in terms of a manifested mass defect appears seriously flawed, essentially deriving from the inherent inaccuracies of the early mass spectrographic measurements and related studies. This also indicates that the idea of nuclear fusion as a source of energy may be dubious.

There is apparently a renewal of interest in harnessing fusion energy in view of the perceived need to decrease dependence on fossil fuels, which are believed to be the primary cause for the accumulation of greenhouse gases leading to global warming. However, the greenhouse theory itself may be essentially invalid as it apparently ignores a possible major alternative route for the absorption of solar radiation on Earth.

The Greenhouse Theory of Global Warming

Solar energy and its terrestrial trapping mechanisms; Raman scattering

Solar energy must perforce reach Earth as radiation, as the vacuum existing in outer space rules out conduction and convection mechanisms. The energy thus received by Earth can be directly absorbed by the various elements on the terrestrial surface (Earth's crust, biological matter, etc.). Much of the solar radiation reaching Earth is in the visible range, although with substantial ultraviolet (UV) and infrared (IR) components [2].

The visible part absorbed by the various elements on the terrestrial surface can ultimately manifest as heat *via* internal-conversion processes. Fluorescent relaxation would also emit longer wave-length radiation, including IR. Likewise, the IR part of solar radiation can also be absorbed and end up as heat.

The two major constituents of Earth's atmosphere, nitrogen and oxygen, are incapable of absorbing IR radiation, as they are symmetrical diatomics at the molecular level. However, nitrogen and oxygen can – effectively – absorb IR radiation *via* Raman scattering of the incident visible light. This would appear to be the major pathway for the warming of Earth's atmosphere by solar radiation.

Certain gases present in trace amounts in the atmosphere, notably carbon dioxide, methane and water vapour, can and do absorb IR radiation, which is subsequently converted to heat. It is currently believed that these gases thus form a partially reflecting canopy that prevents IR radiation from exiting Earth to space. (This implies that without the greenhouse gases Earth would suffer cataclysmic cooling, particularly after nightfall.) Qualitatively, this is the basis of the 'greenhouse' theory of global warming and climate change.

However, it would appear that the greenhouse effect would be marginal compared to the continuous and large-scale trapping of heat *via* the above Raman scattering mechanism. (Note that this would also apply to reflected visible light, an effect which would overwhelm the conventional greenhouse effect.) In fact, the greenhouse gases would indeed prevent at least part of the solar IR from reaching Earth's surface, which would balance the greenhouse effect to an extent. Thus, current views on global warming may need a drastic reappraisal, although other reasons do indeed exist for reducing toxic emissions from the combustion of fossil fuels.

Alternative Energies and Nuclear Fusion

Whilst the burning of fossil fuels indeed needs to be curtailed from the current high levels for several reasons, their impact on global warming may be minimal. The idea that nuclear fusion is an attractive alternative to fossil fuels also needs further scrutiny, as fundamental theoretical doubts remain as to the viability of fusion. (In fact, that nuclear fusion needs to be initiated by a prior fission event complicates understanding the viability of fusion.) The following discussion reinforces previous arguments about fusion, whilst introducing new and valid arguments for doubting the greenhouse effect and the current theory of global warming.

DISCUSSION

The Case Against Nuclear Fusion

Mass spectrographic inaccuracies; 'mass defect' as an artefact

The nuclear binding energy curve is unlikely to be valid for a number of reasons [1]. Primarily, the purported mass spectrographic value for the atomic weight of hydrogen of 1.00778 assumes a level of accuracy – to 6 significant figures – that is not warranted by the methods employed. Thus, the magnetic and electrical field strengths were not defined to anywhere near this level of accuracy. The precision claimed in the measurement of the lines is also unwarranted, as the position of their mid-points is ambiguous.

Thus, the near concordance of the above mass spectrographic value of the atomic weight of hydrogen to the classical value (1.008) appears dubious. In fact, the classical value is itself dubious because of several experimental uncertainties in the determination, particularly the possibility of the enhancement of the deuterium content and other isotope effects.

In fact, small positive deviations from the expected Prout's Law value are the rule rather than the exception for most other elements, and is not unique to hydrogen. Nor can these deviations be explained away as arising from isotopic composition, as the deviations exist even for atoms with only one isotope.

Thus, the mass defect is a consequence of the 'up-marking' of the hydrogen atomic weight relative to the oxygen standard of 16.0000, which practically invalidates the nuclear binding energy curve, and casts a shadow over the theory of nuclear structure as a whole.

Also, the binding energy curve requires that among the lower mass number elements, nuclear stability increase with mass (the theoretical basis on which hopes for fusion rest). However, this is apparently against the mass-energy equation ($E = mc^2$), by which the increase in energy with mass would overwhelm the purported mass defect.

The two nuclear forces

The current theory of nuclear structure is based on a balance between a repulsive electrostatic force (E_F) and an attractive strong nuclear force (N_F). The experimentally observed nuclear binding energy curve is explained by assuming that E_F is weaker than N_F for the lower mass elements, but that E_F increases more rapidly with mass than does N_F. Thus, E_F apparently overwhelms N_F beyond ^{56}Fe, thus explaining the instability and radioactivity of the uranium series. However, this argument seems to neglect nearest neighbour interactions in the case of N_F, which would also increase with mass, size and number of interactions.

In fact, it is noteworthy that the uranide atoms possess a greater mass defect (hence greater stability) than most of the lower mass atoms! These arguments indicate that there are serious ambiguities in the current theory of nuclear structure, as also the interpretation of their experimental basis.

High resolution mass spectrometry and exact masses

Despite the above ambiguities surrounding the mass defect concept, the exact masses determined by modern high-resolution mass spectrometers (HRMS) intriguingly display the same trends as seen with the early mass spectrographs. Also, the HRMS masses are highly reproducible and consistently lead to expected molecular formulae and (ultimately) structures. This implies that the HRMS masses deviate – however subtly – from the Prout's Law values for reasons other than the 'mass defect'.

A very likely reason could be that an atomic nucleus cannot be seen as a point mass and charge, but rather possesses a characteristic size and shape depending on its overall nucleon count and composition. Thus, each nucleus would possess a characteristic polarizability, hence would react to the electrical and magnetic effects within a mass spectrometer in a characteristic way. It is a testament to the precision of modern HRMS instruments that they are able to discern these fine – although purported – mass differences between atoms.

It is, however, ironical that in every case the modern HRMS values follow the same trends as the artefactual early mass spectrographic values, insofar as the masses of the elements lighter than oxygen are overestimated and those of the elements beyond oxygen are underestimated!

It would appear that the HRMS masses represent the characteristic ‘signature’ of each atom, essentially reflecting the polarizability differences between different nuclei. If then the masses of hydrogen and oxygen are assigned as in the early mass spectrographic cases the same quantitative trends would be found even in the HRMS cases.

It is particularly noteworthy that the classical (chemical) atomic weights were – more often than not – greater than the expected Prout’s Law values, even for elements with a single known isotope. It is on this basis, apparently, that the early mass spectrographic studies *assigned* the exact mass of the hydrogen atom as 1.00778. (This is intriguingly close to the classical value of 1.008, and in any case the possibility of an assignment is justified in view of the unwarranted accuracies assumed, *vide supra*.)

The point is, why do the older mass spectrographic studies reproduce the overestimated mass in the case of hydrogen but not generally (particularly beyond oxygen)? (In other words, why is the classical value acceptable only for hydrogen?) It is, therefore, difficult to avoid the conclusion that the modern HRMS results are also – to an extent – artefactual, notwithstanding their utilitarian value in molecular formulae determinations.

An explanation for the observed trends could well be that increasing nuclear polarizability leads to corresponding negative deviations from Prout’s Law values. Then, employing the oxygen standard (16.0000, *i.e.* zero deviation from Prout’s Law) leads to the ‘observed’ value for hydrogen (1.00778). (Having hydrogen as 1.00000 would imply a large negative deviation for oxygen.) The close concordance between the classical value and the mass spectrographic value in the case of hydrogen, however, is best viewed as a coincidence (if not an assignment).

Fission and fusion: the continuing search for the holy grail

Although nuclear fission is well established, the case for nuclear fusion does not rest on firm foundations, based on the above arguments. It is indeed noteworthy that there is scant experimental evidence for fusion of any type. The problem is compounded by the claim that fusion needs to be initiated by fission or other energy yielding phenomena, deemed necessary to overcome the energy barrier to get two nuclei to fuse together. Thus, it would be difficult to separate the energy output from the two processes.

Interestingly, although fission was known to be enormously exergonic, a considerable kinetic barrier and consequent low reaction rate initially prevented fission’s practical application. The kinetic problem was ingeniously solved by employing the chain reaction strategy, which enabled a rapid accumulation of energy that could be tapped for various purposes. However, the dangers of radioactive contamination have continually plagued nuclear fission and its exploitation for human welfare.

Nuclear fusion, apparently, is thus seen as an attractive and relatively ‘clean’ alternative to fission. Hence, fusion has served as a holy grail in energy research, apparently promising a boundless source of clean energy. However, it needs emphasizing that the theoretical basis for fusion appears fundamentally flawed on several grounds, so a more circumspect approach to major investments is indicated.

The Greenhouse Effect, Global Warming and Climate Change

The trace-gases canopy theory and the greenhouse effect

The sun’s rays bombard Earth with bountiful energy during the daylight hours. For the most part, solar radiation consists of visible light, although it is accompanied by varying amounts of ultraviolet (UV) and infrared (IR) components. It is currently believed that Earth would be uninhabitably cold in the absence of a mechanism for the conversion of a large part of the solar radiation into heat, and its subsequent retention.

There are indeed many terrestrial features, from the ground itself to vegetation in all its forms, that can and do absorb a great deal of the impinging solar radiation. Standard photophysical theory indicates that absorption is followed by relaxation and fluorescent emission at a lower energy than that of the incident radiation. Accordingly, absorption towards the red end of the visible spectrum would result in fluorescent emission of IR radiation. The above relaxation would occur *via* internal conversion mechanisms to lower vibrational states with loss of heat (and possibly IR emission).

The IR radiation thus emitted would be released into outer space, essentially because the major constituents of Earth’s atmosphere (N_2 and O_2) are not IR active, as these symmetrical diatomics cannot undergo a change in dipole moment. Thus, an alternative IR-trapping mechanism is needed to retain the IR radiation on Earth. It is believed that this is performed by a handful of IR-active gaseous compounds, particularly carbon dioxide (CO_2), methane (CH_4) and water vapour (H_2O), which are present in trace quantities in the atmosphere. These gases absorb the IR radiation emitted from Earth’s surface (at select wavelengths) and emit part of it back to Earth (and the remainder to outer space). Thus, at least a part of the terrestrial IR radiation is retained by Earth, preventing catastrophic levels of cooling.

The above IR-active gases thus form a partially reflecting canopy that allows only a part of the incoming solar energy to exit back to outer space. This is thus termed the 'greenhouse effect' in analogy to a real greenhouse (of the garden variety), and the said gases 'greenhouse gases'. Although normal levels of the above IR-active greenhouse gases would maintain an acceptable energy balance – hence comfortable temperatures on Earth – excessive levels of the greenhouse gases would lead to correspondingly excessive warming of Earth.

It is currently believed that excessive levels of CO_2, resulting from the combustion of fossil fuels for a variety of activities of importance to modern civilization, have upset the normal energy balance by an increase in the greenhouse effect and consequent warming. CH_4 has also been implicated in such 'global warming', although it is produced as a by-product of certain metabolic processes rather than *via* combustion.

A critique of the greenhouse theory of global warming

General considerations. The greenhouse theory of global warming seems oversimplified, for several reasons. It is particularly noteworthy that heat largely resides in various states of matter as the kinetic energy of their molecular constituents. This is essentially translational energy, although accompanied by vibrational and rotational components. Also, there are a number of ways in which the incident solar radiation can be converted to heat on Earth.

Raman scattering, etc. An intriguing possibility is the Raman scattering of visible light by the major constituents of Earth's atmosphere (N_2 and O_2). These symmetrical diatomics are IR inactive as they cannot undergo a change in dipole moment upon vibrational excitation; however, they can undergo Raman scattering as they experience a change in polarizability upon vibrational excitation. Raman scattering is inelastic scattering, a part of the incident light being retained by the scattering molecule as vibrational energy, which would be dissipated into other modes, thus manifesting as heat.

Although Raman scattering can occur *via* either absorption of energy (Stokes shifted) or release of energy (anti-Stokes shifted), the former is known to predominate (as it occurs from the predominant vibrational ground state). Again, although the elastic Rayleigh scattering predominates relative to the Raman scattering modes, the sheer volume of the atmosphere and the plentiful availability of light (for a substantial period during the daylight hours) likely indicate that Raman scattering would lead to substantial absorption of energy. (This is not to say, of course, that Raman scattering is the reason for global warming!)

Many terrestrial constituents, such as soil, rocks and vegetation, would also absorb various parts of the incident solar radiation, particularly visible light (the major component). The absorbed light energy, as noted above, would ultimately manifest as heat. Vast water bodies would absorb the IR component of solar radiation thus effecting a relatively direct conversion to heat.

Furthermore, although Raman scattering by atmospheric N_2 and O_2 has indeed been recognized previously [3], it has to be viewed alongside a range of phenomena related to energy uptake and distribution, as discussed below. It is particularly noteworthy that Raman scattering offers an additional mode of solar energy absorption, as in any case the Earth's crust itself is significantly heated by solar radiation. Thus, the validity of the greenhouse theory depends on how effectively the greenhouse gases prevent the energy absorbed – by whatever means – from exiting Earth. Intriguingly, in fact, an important mode of energy dissipation appears to have been ignored so far.

<u>Interconversions, absorbers and emitters</u>. The interconversion of heat energy between the various modes (translational, vibrational and rotational) is to be expected – assuming an extension of the equipartition principle. Furthermore, the conversion of heat energy to radiant energy was a particular concern of classical physics, indeed the study of blackbody radiation having spurred the development of quantum theory. (A low temperature body such as Earth is also expected to emit long wavelength, including substantial IR, radiation.)

It is noteworthy and pertinent that a good absorber is also a good emitter. Thus, a greenhouse gas would also be a good emitter of IR radiation, noting that such emission can and does occur from thermally excited states at normal temperatures. (Thus, every object has its IR imagery, which is indeed the basis of night vision technology.) Clearly, then, the greenhouse gases would be expected to facilitate the (partial) dissipation of terrestrial heat to space *via* the emission of IR radiation!

It is also pertinent that the effective absorption of IR *via* Raman scattering is irreversible, and that IR emission is also forbidden from N_2 and O_2. (This indeed makes night vision technology possible!) Thus, much of the solar energy trapped *via* scattering cannot leave Earth by any direct means. However, collisional transfer of energy from N_2 and O_2 to a greenhouse gas, followed by IR emission is entirely feasible, and would lead to cooling. The transfer of energy from other terrestrial elements *via* collision with (abundant) molecules of N_2 and O_2 to a greenhouse gas, followed by IR emission, would also lead to cooling.

Intriguingly, also, the greenhouse gases would absorb some of the incident solar IR radiation, and re-emit a part of it back to outer space, preventing a corresponding rise in temperature. All the above processes indicate that the presence of greenhouse gases leads to cooling rather than heating, as claimed in the greenhouse theory.

Essentially, therefore, several mechanisms exist for both the absorption of incident solar radiation and the dissipation of the absorbed energy including *via* IR emission. The balance between these various modes of energy transfer and exchange determines the net retention of solar energy by Earth. Although it is not easy to discern the efficiency and contribution of each of these modes to the overall energy balance, irreversible energy uptake *via* Raman scattering by the predominant atmospheric constituents (N_2 and O_2) and the fact that the greenhouse gases can also function as efficient IR emitters deserve serious consideration in any theoretical model.

Equilibrium theory and the greenhouse effect

<u>Detailed balance considerations</u>. That the greenhouse gases facilitate the radiative emission of heat (as IR) is to be expected by equilibrium theory, as vibrational energies fall within the range of available thermal energies. Thus, a small fraction (~ 1%) of vibrationally excited states of the greenhouse gas molecules would exist at normal temperatures, their relaxation emitting IR radiation. (Indeed, anti-Stokes Raman scattering occurs from such excited states.) The principle of detailed balance would then require that the rates of emission and absorption of IR be equal at equilibrium.

In the absence of an externally incident IR radiation (*i.e.* upon nightfall), a steady net emission of IR to outer space would occur. Furthermore, the principle of detailed balance (also known as the principle of microscopic reversibility) is generally considered not to apply to the radiative transfer of energy (*e.g.* photochemical reactions). Interestingly, however, this cannot be valid in the case of IR absorption and emission, as these can also occur *via* thermal excitation. Thus, IR emission and absorption merely provide a pathway for the attainment of thermal equilibrium, a necessary condition for detailed balance to apply.

<u>Competition between radiative and non-radiative energy transfers</u>. The validity of the above arguments, in fact, depends on the relative rates at which the greenhouse gas molecules are excited by radiative and other means. Thus, if the non-radiative transfer of energy is relatively weak, the original greenhouse effect may well prevail.

Furthermore, it is noteworthy that IR excitation of the greenhouse gases only occurs at certain characteristic wavelength ranges at select locations in space (where a greenhouse gas molecule is to be found); at other locations the atmosphere would be largely transparent to IR. However, collisional thermal activation of greenhouse molecules would be a continuing dynamic process, the concentration of excited species being only limited by the Boltzmann Law. These arguments apparently indicate that the emission of IR radiation (from the greenhouse gases) *via* the thermal activation route may well predominate, thus leading to net cooling.

Final comments. The above uncertainties in the greenhouse theory of global warming, of course, do not imply that global warming is not real! However, in view of doubts about the fundamental basis of the greenhouse theory, it is worth considering global warming within a larger scenario of climate change, possibly involving many known and unknown effects operating in a complex dynamic. (In fact, although emissions of toxic gases indeed need to be curtailed, the biological effects of CO_2 are complex, as a certain level of it – obtained metabolically – is deemed necessary for maintaining mental calm and normalcy.)

CONCLUSIONS

Nuclear Fusion

Nuclear fusion is being increasingly viewed as an attractive alternative energy source, because of continuing concerns about global warming induced by the greenhouse effect. However, the fundamental basis of nuclear fusion remains highly questionable, as the theoretical framework based on early mass spectrographic work appears dubious. In particular, the idea of the mass defect and the derived nuclear binding energy curve appear invalid.

Thus, although nuclear fission is well established in both theory and practice, the case for fusion is apparently unsubstantiated (at least in the civilian domain). Although it appears that attempts to effect nuclear fusion would continue, the status of investments and the possibility of success are fraught with uncertainty.

The Greenhouse Effect Theory

Global warming and climate change have caught the imagination of both the scientific fraternity and the general public in no uncertain a manner! The key theory of climate change attributes global warming to the increase in the concentrations of certain trace gases in the atmosphere, particularly CO_2, CH_4 and H_2O. These are currently believed to prevent a part of

Earth's heat from escaping (to outer space) *via* the trapping of IR radiation emanating from various objects on Earth's surface.

However, the essential theory of the greenhouse effect could be oversimplified, particularly in neglecting the trapping of incident solar radiation *via* Raman scattering by the major constituents of the atmosphere (N_2 and O_2), and the possibility that the greenhouse gases can lead to cooling *via* thermal excitation and IR emission (to outer space). The overall mechanism by which solar energy is absorbed and retained on Earth is clearly very complex, and further studies and discussion are indicated before the role of the greenhouse gases can be ascertained. Thus, although global warming appears real, reasons other than the increasing presence of greenhouse gases may be important.

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