Stimulated Emission of Radiation in a Nuclear Fusion Reaction*

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This letter claims that process of stimulated emission of radiation can be used to induce a fusion reaction in a HD molecule to produce $^3$He. An experimental set-up for this reaction is presented. It is proposed to study the technical potential of this reaction as an energy amplifier.

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Standard techniques for nuclear fusion require high temperature and pressure to overcome the Coulomb barrier of the repulsing forces between the reaction partners. Here, a completely different approach to fusion is discussed. The electromagnetic, exothermic fusion reaction

$$p + d \rightarrow ^3\text{He} + \gamma \quad (Q = 5.49 \text{ MeV})$$

(1)

is well known as part of the solar cycle [1,2]. The incoming photon has to have the same energy, i.e. it also has to have an energy which is 5.4 keV below the $Q$-value of the reaction (1). A characteristic property of the process of stimulated emission is that the two outgoing photons are coherent, meaning that their wave functions have the same phase and that the two photons occupy an identical element in the phase space. To match this requirement, the incoming photon has to have the same energy, i.e. the spontaneous emission

$$\text{HD} \rightarrow ^3\text{He} + \gamma,$$

(2)

the absorption

$$\gamma + ^3\text{He} \rightarrow \text{HD},$$

(3)

and the stimulated emission

$$\gamma + \text{HD} \rightarrow ^3\text{He} + 2\gamma.$$  

(4)

The spontaneous emission happens at finite time and is given by the quantum mechanical tunneling of the p,d nuclei across the Coulomb barrier. The repulsing forces between the nuclei are many orders of magnitude larger than the molecular binding forces. Therefore the spontaneous emission is largely suppressed to a negligible probability and is only of academic interest.

The absorption process $\gamma + ^3\text{He} \rightarrow p + d$ is well known in literature, is called photodisintegration and has been measured previously [3,4]. Its cross section has a maximum of about 0.8 mb at a photon energy of 12 MeV. Neglecting the binding electrons, the process from Eq. (3) is given by the photodisintegration cross section close to threshold.

The process of interest is the stimulated emission. In this case the fusion process is induced by the electromagnetic field of a 5.49 MeV initial photon. This field has more energy than needed to overcome the Coulomb barrier of the p,d-system. A proton energy below 0.3 MeV has been shown to be sufficient to induce a fusion reaction $D(p,\gamma)^3\text{He}$ with a cross section of 1 $\mu b$ [5]. The stimulated emission by a 5.49 MeV photon requires no tunneling, with the effect, that the suppression factor which is present in the spontaneous process does not apply here. By formally adding a photon on both sides in Eq. (3): $2\gamma + ^3\text{He} \rightarrow \text{HD} + \gamma$ the analogy between the processes of absorption and of stimulated emission is demonstrated.

From energy-momentum conservation follows that due to the recoil of the $^3$He nucleus the energy of the emitted photon is $\Delta E_{\text{red}} = 5.4$ keV below the $Q$-value of the reaction (1). A characteristic property of the process of stimulated emission is that the two outgoing photons are coherent, meaning that their wave functions have the same phase and that the two photons occupy an identical element in the phase space. To match this requirement, the incoming photon has to have the same energy, i.e. it also has to have an energy which is 5.4 keV below the $Q$-value of the reaction (1). This means that the cross section of the stimulated emission as a function of the photon energy is a $\delta$-function at $E = Q - \Delta E_{\text{red}}$. Due to the long lifetime of the HD molecules, there is no measurable intrinsic width of this resonance. The effective width $\delta E_{\text{eff}}$ of the resonance is determined by the Doppler motion of the HD molecule and by the electronic excitations of the $^3$He final state. Nuclear excitations of the final state are not discussed here. They lead to additional distinct resonances at lower photon energy. The Doppler motion depends on the temperature of the HD target and is small, especially for a cryogenic target. As there is no special mechanism to accelerate the shell electrons, it is natural to assume that the ionization energy of $^3$He is a good approximation for the energy uncertainty of the final state. The ionization energy is 79 eV [6]. This leads to an extremely peaked resonance with a relative width of the order of $\delta E_{\text{eff}}/E \approx 1.4 \cdot 10^{-5}$.

The actual size of the cross section at the peak is hard to estimate. A general thermodynamic consideration as in Ref. [6] leads to the conclusion that the transition probabilities for absorption and for stimulated emission have to be identical in order to be compatible with the

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Planck law of black body radiation. Assuming that this consideration can be applied to our process, the cross section has to have the same order of magnitude as the absorption cross section from Eq. (3).

In trying to understand the process of stimulated emission on the microscopic level, the following considerations might be of interest. The Coulomb barrier of the p,d-system keeps the wave functions of the two nuclei separated to molecular distances, i.e. to a distance which corresponds to a fraction of the average separation of the nuclei in the HD molecule which is 0.74·10^{-10}m [3]. Due to the large distance, an incoming photon will usually react incoherently with one of the nuclei, and the chance that the struck nucleus will react in a second step with the other nucleus is unlikely and defined by the fusion cross section which is in the µb range [3].

The process of stimulated emission requires a coherent reaction of p and d. The phrase ‘coherent reaction’ in this context means that the photon reacts with the total quantum system of the HD molecule instead with the individual nuclei. As the p and d wave functions do not overlap, it is required that the photon has a spatial extension which is large enough to overlap with both wave functions. The longitudinal extension of an individual photon, i.e. of its wave package, is defined by the coherence length of the individual photon. Here, photons with a coherence length of molecular dimensions are required. From the Heisenberg uncertainty principle follows that the photons which are produced by stimulated emission fulfill the requirement, as their energy is determined with a resolution of the order of ~ 80 eV and therefore their longitudinal extension has to be larger than \( \hbar c \cdot (80 \text{ eV})^{-1} = 0.25 \cdot 10^{-7} \text{m} \). This means that photons from HD fusion have a coherence length which is sufficient to stimulate further fusion reactions.

A way to visualize the coherent process in a semiclassical way is to imagine that the electromagnetic field of such a photon raises for a short moment the energy of the two nuclei above the Coulomb barrier. Once the energy of the nuclei is above the barrier, the wave functions of the nuclei can expand, fluctuate and occasionally overlap. Even if the overlap happens only for a short moment, nuclear forces will immediately lead to a collapse of the wave functions into the low-energy \(^3\text{He}\) state. There is no quantum number violation which prohibits the stimulated fusion reaction and the author is not aware of any other mechanism which suppresses this process beyond the typical electromagnetic cross sections. A simple order of magnitude estimate of the cross section is given by the magnetic dipole photon absorption cross section [3]

\[
\sigma \approx 4E \cdot 0.48 \text{ mb/MeV} = 10.5 \text{ mb}. \tag{5}
\]

The factor 4 comes from adding the amplitudes for the two nuclei coherently.

As in a laser device, the reaction of stimulated emission can be used as photon amplifier. A necessary criterion for a laser to work is the population inversion of the laser transition. In our case the population inversion corresponds to the case that there are more particles in the HD state than in the \(^3\text{He}\) state. This criterion is trivially achieved in any HD target. As in an ordinary laser the stimulated emission works iteratively, i.e. the emitted photons induce further processes of stimulated emission while they pass through the laser material. The final intensity grows approximately exponentially with the length of the target.

To initiate the reaction, a photon from an external source is required. A usual external source typically does not fulfill the coherence length requirement, as e.g. photons from typical nuclear reactions have nuclear dimensions, and therefore it is unlikely that those photons will induce stimulated emission. Instead, photons from coherent bremsstrahlung are emitted in a collective process where several nuclei in a crystal are involved [1,2]. Therefore, the individual photons from coherent bremsstrahlung can have a coherence length which has molecular dimensions and therefore might be able to induce the process of stimulated emission in a HD target.

Up to now, no background processes have been taken into account. The HD target serves only as photon amplifier when the cross section of stimulated fusion is larger than the cross section of other electromagnetic processes at this energy like e.g. pair production or bremsstrahlung. The total cross section of background processes for an unpolarized beam and target is 160 mb/molecule, as calculated from Ref. [10]. If the rough cross section estimate of Eq. (3) is correct, the background dominates and the photon beam is exponentially attenuated instead of amplified. Nevertheless, nuclear binding energy is released when an external beam hits the HD target. To improve the fusion to background ratio, it can be considered to spin polarize the photon beam and the HD target.

A possible scenario for an experiment to study the fusion process and the energy amplification is sketched in Fig. 4. A beam with 5.49 MeV photons that have a large coherence length is generated by coherent bremsstrahlung of an electron beam incident on a crystal. The photons hit a liquid or solid HD target. A calorimeter measures the energy of individual photons. If the process of stimulated emission exists, it will show up as coincidence of two or more photons in the same calorimeter element which add up their deposited energy. A peak at 2·5.49 MeV = 10.98 MeV will appear in the energy spectrum of the calorimeter. A second target which contains a mixture of \( \text{H}_2 \) and \( \text{D}_2 \) should not show the effect. A photon beam with a high duty cycle is preferred for this experiment to reduce random coincidences. Once the effect has been demonstrated, it can be considered to repeat the experiment with a spin-polarized target and beam to enhance the signal to background ratio. Experimentally, the techniques of controlling the polarization of HD targets [3] and coherent bremsstrahlung beams [4] are well understood.

To summarize, it is claimed that the process of stimu-
lated emission of radiation can be used to induce a fusion reaction in HD to produce $^3\text{He}$. Thermodynamic considerations suggest that the cross section of stimulated fusion is related to the cross section of photodisintegration of $^3\text{He}$ at threshold. From energy momentum conservation in connection with the almost infinite lifetime of initial and final state follows that the cross section as function of photon energy is a sharp resonance. If a set-up can be found where this or a similar reaction exceeds other competing electromagnetic processes, the stimulated emission can be technically used as an energy amplifier which is fueled by nuclear energy. First order of magnitude estimates indicate an insufficient size of the cross section with the consequence that this process cannot be used as photon amplifier. However, it is estimated that the cross section is in a range where the process can be experimentally demonstrated. This letter is meant as an invitation to calculate and measure the cross section of stimulated fusion or to prove that this process does not exist.

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FIG. 1. A possible set-up for an experiment to study the stimulated emission of photons in the fusion process $p+d \to ^3\text{He}+\gamma$. A photon beam hits a (liquid) HD target and induces fusion processes. The photons are detected in a calorimeter.