# Comment on "Laser Enhancement of Nuclear $\beta$ Decay"

In a recent Letter[1] the possibility of laser enhancement of nuclear $\beta$ decay was proposed. The effect was governed by the dimensionless parameter $\nu = eA/mc^2$, where $A$ is the magnitude of the laser's vector potential. In this Comment we point out that the appropriate potential is not $A$, but rather the vector potential experienced by the nucleus, $A_n$. $A_n$ differs from $A$ because of shielding by the atomic electrons.

In response to the applied field, $\vec{E}$, the atom develops an electric dipole moment.

$$Ze\vec{R} - \sum e\langle\vec{r}_i\rangle = \alpha(\omega)\vec{E}, \tag{1}$$

where $\vec{R}$ is the nuclear coordinate, $\vec{r}_i$ is an atomic electronic coordinate, and $\alpha(\omega)$ is the dynamic polarizability at the laser frequency $\omega$. Since the atom is neutral, its center of mass remains fixed (nonrelativistically), and so

$$M\vec{R} + m\sum\langle\vec{r}_i\rangle = 0. \tag{2}$$

Finally, the nucleus responds to the field seen by it, $\vec{E}_n$, in accordance with Newton's second law $-\omega^2 M\vec{R} = Ze\vec{E}_n$, where $M$ denotes the nuclear mass. Thus

$$\begin{aligned}\gamma = E_n/E = A_n/A \\ = -m\omega^2\alpha(\omega)[Ze^2(1+Zm/M)]^{-1}.\end{aligned} \tag{3}$$

The new relevant parameter is thus

$$\nu_n = \gamma\nu \simeq -\omega^2 A\alpha(\omega)[Zec^2]^{-1}, \tag{4}$$

where we have taken $M/m \gg Z$. The factor $\gamma$ usually tends to make $\nu_n$ much less than $\nu$, and thus to suppress the laser enhancement of $\beta$ decay. However, under certain circumstances it may also increase the effect.

By way of example, consider the case of $^3$H subjected to a laser beam of intensity $10^{18}$ W/cm$^2$ and photon energy 1 eV. For hydrogen the static polarizability is $4.5a_0^3$. For $\hbar\omega = 1$ eV the dynamic polarizability is approximately the same as the static polarizability. Then $\nu = 1.06$, while $\nu_n = 0.0065$. Since $\nu_n \approx 1$ is needed for a significant enhancement, we see that the atomic shielding quenches the effect.

On resonance with an atomic transition, however, $\alpha(\omega)$ becomes large, and $\gamma$ need not be small. For weak $A$, where power-broadening and multiphoton-ionization effects may be neglected, the resonant value of $\gamma$ is $|\gamma_{\text{res}}| = m(\omega\mu/e)^2(Z\hbar\Gamma)^{-1}$, where $\mu$ is a dipole transition matrix element between the resonating states and $\hbar\Gamma$ is the radiative width of the excited atomic state. This is of the order of magnitude of $mc^2/(\hbar\omega Z\alpha)$ which is a very large number. However, if the intensity of the incident field is increased, eventually power-broadening effects enter which limit the size of $\gamma_{\text{res}}$. When the Rabi frequency, $\Omega$, exceeds the radiative decay rate, $\gamma_{\text{res}} \approx m(\omega\mu/e)^2(Z\hbar\Omega)^{-1}$, where $\hbar\Omega \sim \mu E$. Then Eq. (4) becomes

$$\nu_n = \omega\mu/(Zec) \simeq ka_0/Z, \tag{5}$$

where $k$ is the wave vector of the light. From this relation it is clear that $\nu_n$ is a small number for any laser situation.

In summary, our estimates show that laser enhancement of $\beta$ decay is impractical for neutral atoms. Intensity levels as high as those needed for this effect will modify the state significantly by ionization and other effects so that the problem becomes much more complex than it would be in the absence of this dependence. For ions, of course, the field at the nucleus is only partially shielded by electrons and the considerations of Ref. 1 are more applicable. However, the need for ionization will greatly limit the practical applications of laser-enhanced $\beta$ decay.

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[1] W. Becker, W. H. Louisell, J. D. McCullen, and M. O. Scully, Phys. Rev. Lett. <u>47</u>, 1262 (1981).