Compression and focusing of a neutron gas by moving the moderator

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It is shown that when a moderator moves in a neutron gas it is possible to rake the neutrons together and increase their density in the moderator and ahead of the moderator, a fact that can be used to increase the concentration of the reactions induced by neutrons and their energy release, and to enhance self-expansion and self-contraction of a cavity in matter. The possibility of inertial shaking-off and focusing of neutrons by rapid deceleration of matter is demonstrated. The question is raised of the distribution of the neutrons in the medium having a density and velocity distribution.

In a number of scientific and applied problems, it is desirable to increase the density of a neutron gas. By now, under laboratory conditions, [1] a neutron flux density $I \approx 10^{18}$ cm^{-2} sec^{-1} has been attained before or after moderation, as well as a thermal-neutron density $n_T \approx I/v_T \approx 10^{13}$ cm^{-3}, where $v_T \approx 2 \times 10^5$ cm/sec. In this article we note the possibility of increasing the neutron density by moving the moderator in a neutron cloud. This increase is due to slowing down of the neutrons by inelastic and elastic collisions in the moderator, at arbitrary moderator velocities, and the possibility of raking together and throwing-off the neutrons by the rapidly moving walls of the moderator. We point out the practical applications of compressed neutron clouds.

1. Given the moderator velocity $u > v_T$ in a cloud of neutrons with density n_0, then in the coordinate frame of the moving moderator the incident neutron flux is $I \approx n_0 u$. Neglecting reflection, we obtain the neutron concentration n in a diffuse layer of thickness $\delta_D \approx \sqrt{Dt}$ in a moderator, namely

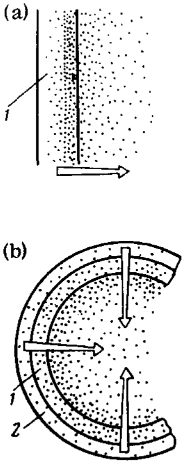
$$n \approx I t/\delta_D \approx I\sqrt{t/D} \approx n_0 u/v_D,$$

where v_D is the neutron diffusion velocity in the moderator, $v_D \approx \sqrt{Dt}$, and D is the diffusion coefficient.

If a neutron density is established at the surface by increasing the backward scattering flux $I_{\text{scat}} \approx n v_T/6$, and if the diffusion flux can be neglected (large diffusion depths and small gradients), then the condition $I \approx n_0 u \approx I_{\text{scat}} \approx n v_T/6$ yields the density-increase coefficient $K \approx n/n_0 \approx 6u/v_T$.

Since the backward flux is proportional to the neutron density inside the moderator at its surface, it follows that the neutron flux density increases also in front of its surface, i.e., raking-up takes place.

The neutron density is particularly strongly increased when a closed geometry is compressed, e.g., when the



Compression of neutron gas by motion of the moderator: a—planar case; b—converging compression: 1—moderator layer, 2—layer of working medium.

walls of the moderator come closer together in cylindrical, spherical, or some other all-around manner. For example, if the wall velocity u exceeds the velocity v_D of the diffusion to the interior, $u > v_D$, then the concentration is $n(t) \sim 1/V(t)$, where V is the volume of the cavity inside the moderator walls. Diffusion to the interior of the moderator increases the effective volume of the compressed neutrons, $V_{\mathrm{eff}} \approx \{R(t) + \delta_D(t)\}^m$, where $m = 2$ for a cylinder and $m = 3$ for a sphere, i. e., $V_{\mathrm{eff \cdot min}} \sim \delta^m(t_{\mathrm{fin}}) \sim Dt_{\mathrm{fin}}^{m/2}$, where t_{fin} is the duration of the compression process and $n_{\mathrm{max}} \sim n_0 V_0 / V_{\mathrm{eff \cdot min}}$.

2. The increase of the neutron density can increase the yield and the volume concentration of the acts of such reactions as $(n\gamma)$, $(n\alpha)$, (nf), and others, which are usually accompanied by an energy release $\epsilon \approx 1$ to 100 MeV. At high neutron density, the volume power release is $W = nv_T n_{\mathrm{nuc}} \sigma_{nx} \epsilon$ can be so large that the medium becomes strongly heated, evaporates, and starts to expand either to the exterior or to the interior (if a cavity is present).

This induced expansion, with ever increasing velocity, can also be used to compress and enhance the action of a neutron flux if, e. g., a layer of moderator moves in front of the moving surface of the working medium and increases not only the neutron density but also the cross section for the interaction of the neutrons with the nuclei. The initial neutron density $n \approx W/v_T n_{\mathrm{nuc}} \sigma \epsilon$ needed to initiate such a process of self-acceleration and self-compression of matter can be estimated (assuming an energy per nucleus $\epsilon_{\mathrm{nuc}} \sim Wt/n_{\mathrm{nuc}} \approx 100$ eV, $v_T \approx 3 \times 10^5$ cm/sec, $\sigma\epsilon_x \approx 10^4$ b MeV, and $t \approx 10$ μsec), at $n \approx \epsilon_{\mathrm{nuc}}/\epsilon_x v_T \sigma t \approx 10^{16}$ cm^{-3}, i. e., a neutron compression by a factor $K \approx 10^2 - 10^3$ suffices.

3. It is interesting to note that when a moderator in which neutrons have accumulated is slowed down, an inertial neutron flux is produced in it, with an instantaneous initial velocity v_0 and with a steady-state velocity $u \approx a/\nu_s$, where a is the acceleration and ν_s is the frequency of the neutron collisions in the moderator ($\nu_s \approx n_{\mathrm{nuc}} \sigma_s v_T$), provided that the diffusion can set in within a time $t \gg 1/\nu_s$ (usually $\nu_s \sim 10^6$ sec^{-1}).

This inertial flux can also be used in practice.

We note that the motion and compression of media in which neutrons diffuse can change the neutron distribution density. In particular, motion of a moderator wall in a neutron-containing medium can increase the neutron density near the wall because neutron departure from the moving wall is slowed down by diffusion. In particular, cases are possible when the velocity of the moderator wall exceeds the velocity at which the neutrons leave the wall, and the wall overtakes and gathers together all the previously scattered neutrons. (In the case of motion in vacuum, which is possible only for monotonic acceleration of the moderator wall.)

If the medium is abruptly decelerated within a distance $L \approx l_s$, then the neutrons continue to move by inertia, a fact that can be used to focus neutrons (e. g., by rapid flow of the medium towards the axis or towards the center and by abruptly changing the velocity vector through deceleration or expansion). The sharpest focusing takes place when the velocity of the medium exceeds the thermal velocity of the neutrons and when the decelerating surface is nearly spherical. For the neutrons to be dragged and trapped by a stream or by compression of the medium it is necessary that the dragging time be $t \ll t_D \approx L^2/D$, where L is the effective diameter of the medium.

The problems raised here concerning the distribution of neutrons in a medium in which there exists a velocity or density distribution is not only of applied but also of theoretical interest. The considered processes whereby the neutron density is increased, and their utilization concentrated, and also the collapse and self-collapse of cavities in media placed in a neutron gas, can be used to attain very high densities by self-compression as well as to obtain neutrons for various neutron-physics problems.

[1] Fizicheskiĭ éntsiklopedicheskiĭ slovar' (Encyclopedic Physics Dictionary), Moscow (1966), Vol. 5, p. 554.