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PEREGRINATIONS ON COLD FUSION

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ABSTRACT

Attention is focused on the possibility of resonance-enhanced deuteron Coulomb barrier penetration. Because of the many-body nature of the interactions of room-temperature deuterons diffusing through a lattice possessing deuterons in many of the interstitial positions, the diffusing deuterons can resonate on the atomic scale in the potential wells bounded by the ascending walls of adjacent Coulomb barriers and thereby penetrate the Coulomb barriers in a fashion vastly underestimated by two-body calculations in which wells for possible resonance are absent. Indeed, perhaps the lack of robust reproducibility in cold fusion originates from the narrowness of such transmission resonances.

I. Introduction

We wish to emphasize in these peregrinations that the global structure of a potential leads to interference effects that influence the transmission through the potential. As an example, it is well known that tunneling through a pair of barriers can be accomplished with a transmission coefficient of unity at certain resonant energies even though tunneling through either barrier separately results in transmission with a coefficient necessarily less than unity.[1]

When one studies the penetration of an isolated one-dimensional potential barrier in quantum mechanics, one learns that if

$$\Psi_j(x) = A_j \exp(ikx) + B_j \exp(-ikx), \quad j = i,f$$

represent the initial (i) and final (f) wave functions of a beam of particles incident from the left on a symmetric potential $[V(x) = V(-x)]$, then

$$\begin{bmatrix} A_i \\ B_i \end{bmatrix} = \begin{bmatrix} \alpha + i\beta & i\delta \\ -i\delta & \alpha - i\beta \end{bmatrix} \begin{bmatrix} A_f \\ B_f \end{bmatrix}$$

where $\alpha^2 + \beta^2 - \delta^2 = 1$.[1] It is clear that the square of the absolute value of the inverse of the (1,1)-element of this matrix yields the transmission coefficient of the beam through the potential barrier since the transmission coefficient, T, is defined to be the ratio $|A_f/A_i|^2$ when B_f vanishes. Thus

$$T = \frac{1}{\alpha^2 + \beta^2} = \frac{1}{1 + \delta^2} .$$

A matrix $\underset{\approx}{M}$ always describes the effect of a one-dimensional potential structure on a plane wave, where

$$\begin{bmatrix} A_i \\ \\ B_i \end{bmatrix} = \underset{\approx}{M} \begin{bmatrix} A_f \\ \\ B_f \end{bmatrix}$$

Suppose we have a sequence of N arbitrary, but symmetric, one-dimensional barriers in which α_j, β_j, and δ_j $(j = 1,2,\ldots,N)$ specify the effect of each potential, in isolation, upon a plane wave. The $\underset{\approx}{M}$ matrix that results from a plane wave being transmitted through such a sequence of barriers is given by

$$\underset{\approx}{M} = \prod_{k=1}^{N} \begin{bmatrix} \alpha_k + i\beta_k & i\delta_k \\ \\ -i\delta_k & \alpha_k - i\beta_k \end{bmatrix} \qquad (1)$$

where $\alpha_k{}^2 + \beta_k{}^2 - \delta_k{}^2 = 1$ for each value of k. Again the transmission coefficient is given by $|M_{11}|^{-2}$. Since T is not simply equal to the product

$$\prod_{k=1}^{N} (\alpha_k{}^2 + \beta_k{}^2)^{-1},$$

the interference effect due to the presence of multiple barriers is evident. One first multiplies together all the matrices on the right-hand side of Eq. (1) before taking the square of M_{11}. For example if N = 2,

$$T = |(\alpha_1\alpha_2 - \beta_1\beta_2 + \delta_1\delta_2)^2 + (\beta_1\alpha_2 + \beta_2\alpha_1)^2|^{-1} .$$

II. Resonance Effects in Tunneling through Multiple Barriers

Figures 1 and 2 demonstrate the possibility that diffusing deuterons can resonate on the atomic scale in the one-dimensional potential wells bounded by the ascending walls of adjacent Coulomb barriers and thereby penetrate the Coulomb barriers in a fashion vastly underestimated by two-body calculations[2] in which wells for such resonance are absent. The figures exhibit the numerical solution of time-independent Schrodinger equation describing a beam of particles incident from the left on a potential barrier V(x) whose maximum height is twice the monochromatic beam energy, E_c. We are presenting the data as a function of $k_o x$, where k_o represents the incident de Broglie wave number of the beam's particles; i.e., $k_o = (2mE_o/\hbar^2)^{1/2}$, in which $\hbar$ represents Planck's constant divided by 2π.

In Figs. 1(a,e), V(x) has been chosen to vanish everywhere except on the domain, $- a - b < x < a - b$, within which it has the parabolic form: $V(x) = V_o\{[a^2 - (x + b)^2]/a^2\}$. In Figs. 2(a,e), however, V(x) has been chosen to have the additional parabolic barrier, $V(x) = V_o\{[a^2 - (x + b)^2]/a^2\}$, on the domain $- a + b < x < a + b$. We have chosen $k_o a = 3.0$, $k_o b = 1.978052\pi$, and, as we have already remarked, $V_o = 2E_o$.

Wherever V(x) vanishes, the Schrodinger wave function $\Psi(x)$ can be represented as $\Psi(x) = A \exp(ik_o x) + B \exp(-ik_o x)$, in which A and B are complex constants representing the probability amplitude for particles traveling to the right and to the left (due to reflection by the barriers), respectively. We have set A = 1 to the left of all of the barriers in order to represent an incident beam of unit amplitude traveling toward the barriers. To the right of the last barrier B = 0 since any particles that have tunneled through the barriers suffer no further reflections. In the region in which $V(x) \neq 0$, we have chosen to define the continuation of these constants, A and B, according to

$$A(x) = \frac{1}{2}\left[\Psi(x) - \frac{i}{k_o}\frac{d\Psi(x)}{dx}\right]\exp(-ik_o x) \quad \text{and} \quad B(x) = \frac{1}{2}\left[\Psi(x) + \frac{i}{k_o}\frac{d\Psi(x)}{dx}\right]\exp(ik_o x) .$$

In Figs. 1, we observe that the single potential barrier leads to a markedly decreased amplitude for particles to get through the barrier. To conserve the probability, we observe that the absolute value of the amplitude for reflection B is essentially unity to the left of the barrier. The probability density, $|\Psi(x)|^2$, for finding particles at the peak of the barrier is 0.045. (See Fig. 1f.)

In contrast, Figs. 2 demonstrate that the presence of a second barrier can lead to resonance. The absolute value of the amplitude A remains at unity after the particles have penetrated through both barriers, implying a transmission coefficient of 100%. The reflection amplitude B is zero to the left of the set of the two barriers. All of the particles penetrate through the double barriers; none are reflected. Between the barriers the absolute values of the amplitudes, A and B, are large and are approximately equal because the particles are trapped between the barriers and reflect back and forth numerous times before they are finally transmitted. As a result, the probability density for finding particles at the peak of the first barrier is enhanced 561 times over that of Fig. 1f to a value of 25.17. (See Fig. 2f.) Of course, the energy E_o (or equivalently, k_o) was chosen to be resonant for this double barrier case.

III. Application to the Possibility of Cold Fusion

Herein lies a possibility for cold fusion. Because of the many-body nature of the interactions of room-temperature deuterons diffusing through a lattice possessing deuterons in many of the interstitial positions, the diffusing deuterons can resonate on the atomic scale in the potential wells bounded by the ascending walls of adjacent Coulomb barriers (analogous to the potential barriers of Figs. 2) and thereby penetrate the Coulomb barriers in a fashion vastly underestimated by two-body calculations (such as that of Figs. 1) in which wells for possible resonance are absent. Indeed, perhaps the lack of robust reproducibility in cold fusion originates from the narrowness of such transmission resonances.

Support for this many-body effect comes from the following "back-of-the envelope" calculation: Suppose we estimate that for a low-energy resonance, $\lambda_{de\ Broglie} = h/p \approx L$, in which L is the internuclear spacing and p is the deuteron momentum. We may associate a thermal temperature with this de Broglie wavelength according to $3K_BT/2 = p^2/2m_D \approx h^2/2m_DL^2$, where K_B is Boltzmann's constant and m_D is the deuteron mass. If T is expressed in Kelvin and L is expressed in Angstroms, we find that

$$T(K) = \frac{318}{L^2(\text{Å})} .$$

For an L equal to 1.04 Å, which is larger than the deuteron separation in a deuterium molecule, one finds that T = 20°C, characteristic of an ambient room temperature. Although cavalierly derived, this formula suggests the increasing importance of large-scale correlations (many-body coherent effects) with decreasing temperature.

IV. Summary

Just as a series of electrons passing through a double slit, even one-at-a-time, result in a double-slit interference pattern, so also thermal deuterons passing through PdD can result in an interference pattern due to the influence of the three-dimensional "multiple slits" of the lattice on the deuterons. The resultant pattern of the deuterons cannot be deduced by each deuteron's interaction with each nucleus, taken one-at-a-time. If cold fusion is a result of interference (assuming for the sake of discourse that cold fusion exists), then one might even expect to find an interference pattern when one searches for the sites of cold fusion.

From these peregrinations, we can conclude that the many-body nature of the interactions of room-temperature deuterons diffusing through a lattice possessing deuterons in many of the interstitial positions can lead to resonating of the diffusing deuterons on the atomic scale in the potential wells bounded by the ascending walls of adjacent Coulomb barriers, thereby resulting in the penetration of the Coulomb barriers in a fashion vastly underestimated by two-body calculations in which wells for possible resonance are absent. Indeed, we have suggested that the lack of robust reproducibility in cold fusion might originate from the narrowness of such transmission resonances.

In order to calculate the effect of this enhanced transmission on the rate of cold fusion, one needs to know not only the structure of the transmission resonances (e.g., their widths) as well as the distribution of states occupied by the deuterons in the neighborhood of these resonances, but also he D-D fusion cross sections at ambient thermal energies. Of course, in no way have we attempted to account for the disparity in the amount of heat released as compared with the number of neutrons produced, which has been alleged by researchers at the University of Utah, Texas A&M University,[3] and Stanford University.[4]

If the experimental results that purport to exhibit cold fusion become more definitive, our analysis should be extended to treat more precisely the actual three-dimensional nature of the PdD system. One must detail the dynamics of the Pd and D nuclei and the electrons, which will take into account Coulomb-screening effects due to pair correlations. Additionally, one must take into account the omnipresent factor of significant deuteron transport resulting from either an applied external voltage or an applied thermal gradient. Clearly, no classical dynamics calculation is relevant. must perforce develop a many-body quantum-mechanical dynamics model.

Acknowledgment

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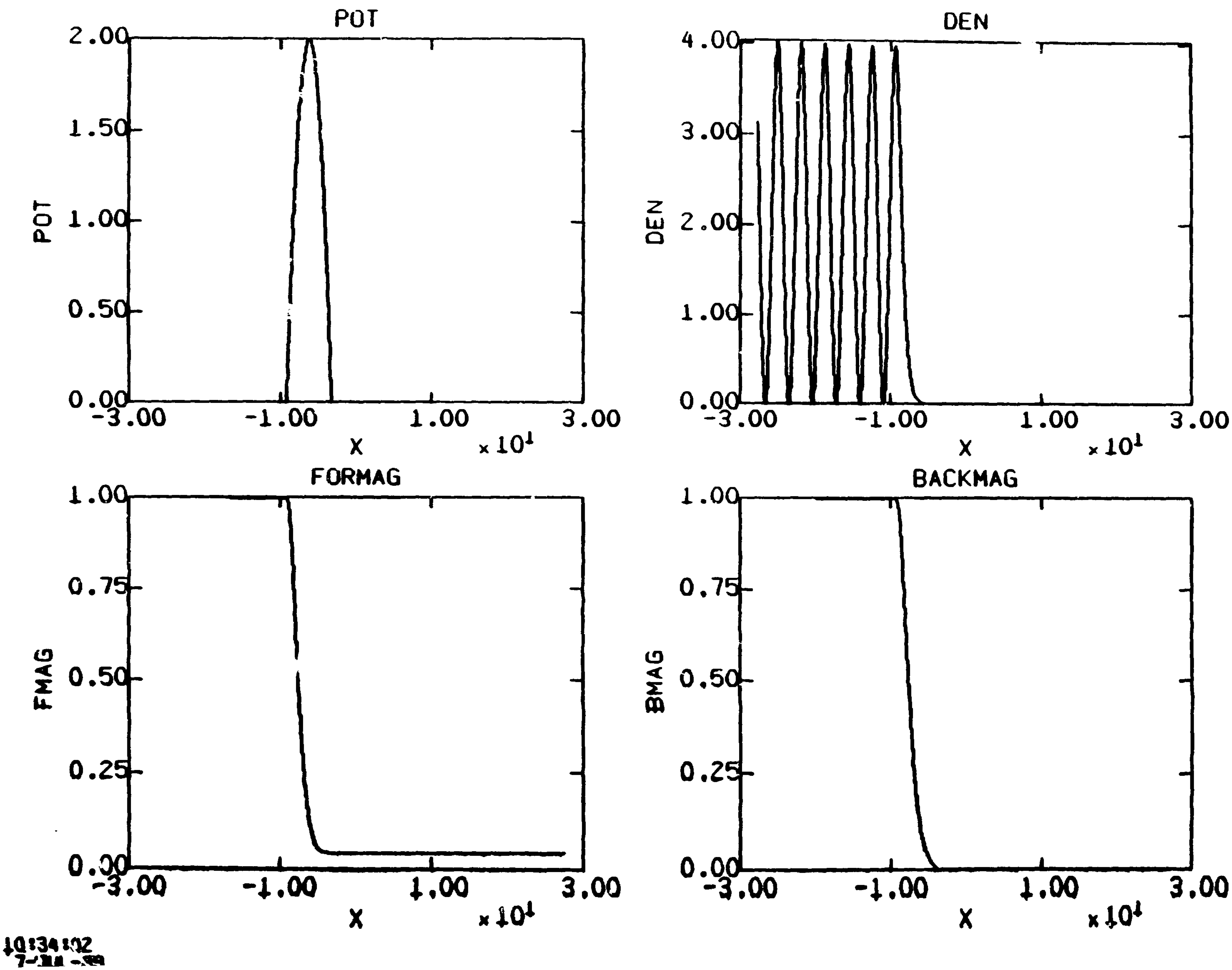
Figures

1. In (a), (b), (c), and (d), respectively, V/E_0, $|\Psi|^2$, $|A|$, and $|B|$ are shown as a function of k_0x for the single barrier potential discussed in the text. In order to emphasize the behavior of these four functions in the neighborhood of the maximum value of the potential barrier, in (e), (f), (g), and (h), respectively, V/E_0, $|\Psi|^2$, $|A|$, and $|B|$ are again shown as a function of k_0x on the restricted domain on which V is increasing to its maximum value.

1. In (a), (b), (c), and (d), respectively, V/E_0, $|\Psi|^2$, $|A|$, and $|B|$ are shown as a function of k_0x for the double barrier potential discussed in the text. In order to emphasize the behavior of these four functions in the neighborhood of the maximum value of the left-hand potential barrier, in (e), (f), (g), and (h), respectively, V/E_0, $|\Psi|^2$, $|A|$, and $|B|$ are again shown as a function of k_0x on the restricted domain on which V is increasing to its first maximum value.



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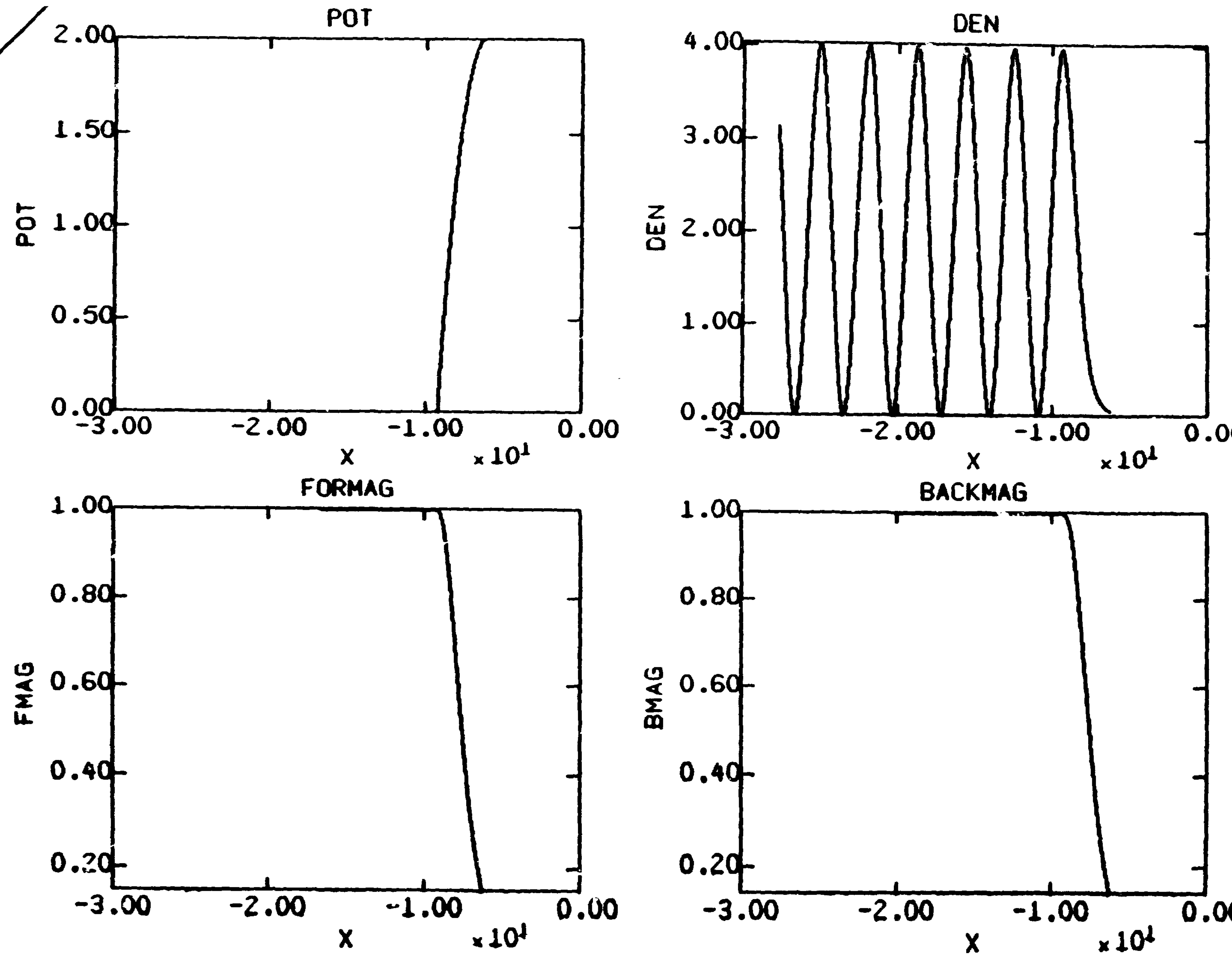

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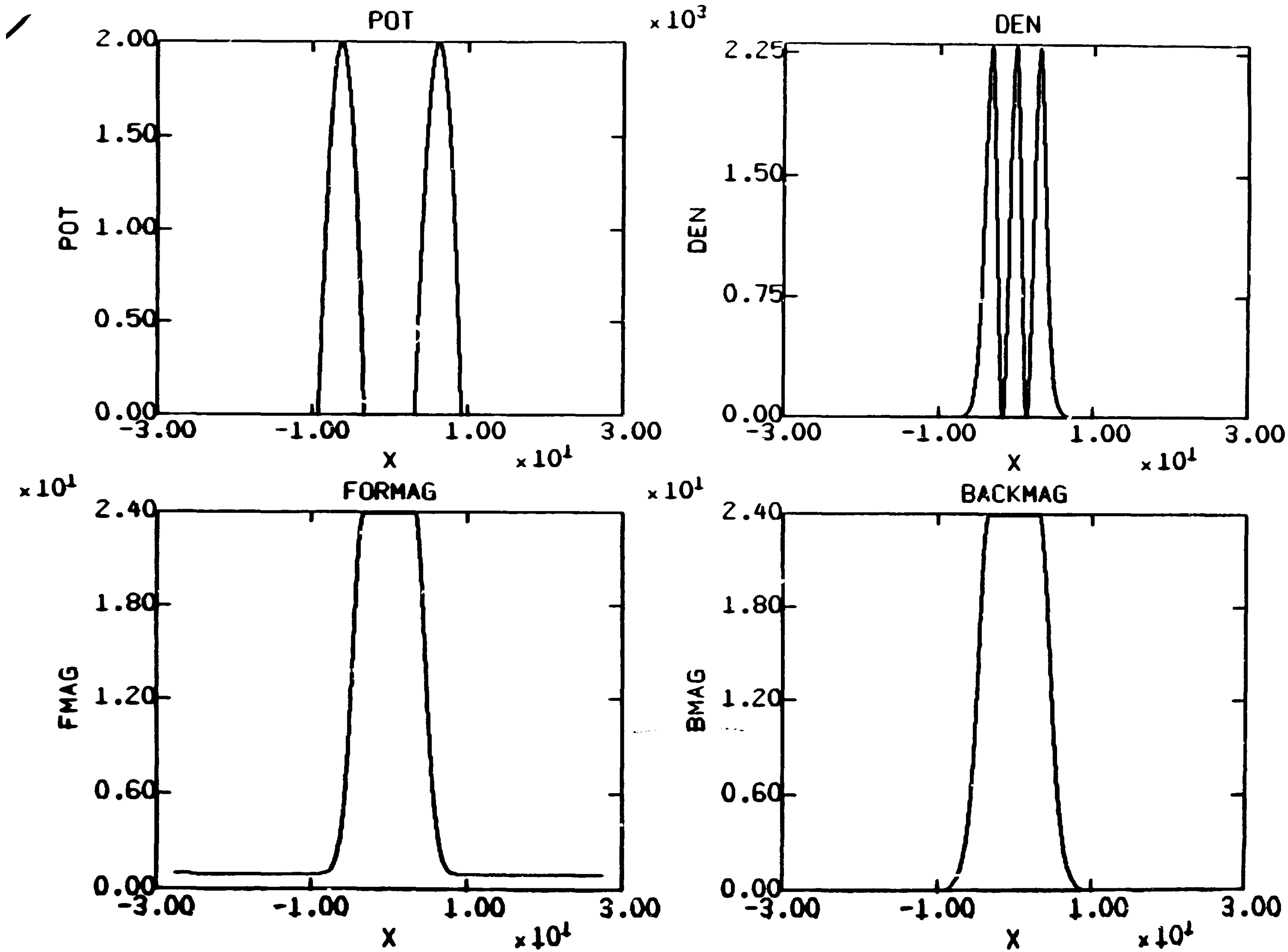
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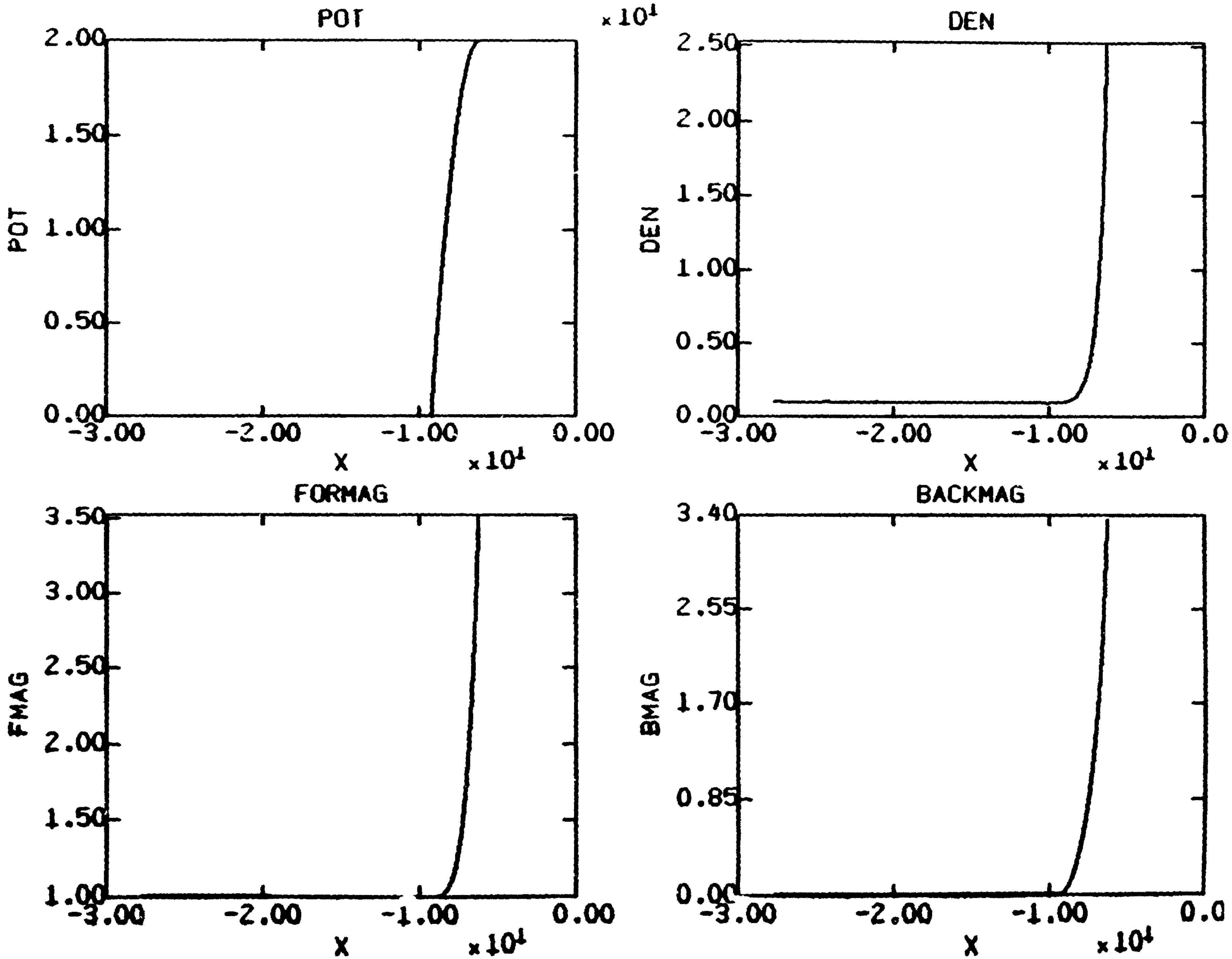
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