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H. FELDMEIER
INSTITUT FÜR KERNPHYSIK, TH DARMSTADT, FRG

Edited by: HANS FELDMEIER

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TIME DEPENDENT HARTREE-FOCK AND ONE-BODY DISSIPATION FOR HEAD-ON COLLISIONS OF $^{84}Kr + ^{209}Bi$ *)

D.M. BRINK

University of Oxford, Theoretical Physics Dept,
1 Keble Road, Oxford, England

Fl. STANCU

University of Liège, Institut de Physique,
Sart Tilman, 4000 Liège 1, Belgium.

The purpose of the present study is to get more insight into the dissipation mechanism of heavy ion collisions. To this end we have made a comparison of the extensive TDHF calculations of head-on collisions of $^{84}Kr + ^{209}Bi$ [1] with predictions of the one body dissipation theory of the Berkeley group [2].

The TDHF calculations [1] show that the projectile is stopped by the target in a very short time of the order of 5×10^{-22} s. Between $E_{lab} \sim 850$ MeV and $E_{lab} \sim 1100$ MeV there is a fusion region. For $E_{lab} < 850$ MeV the projectile "bounces" off the target while for $E_{lab} > 1100$ MeV it "passes through" the target.

Here we define a stopping time t_s as the interval from the instant when the nuclear surfaces touch ($s = 0$) to the instant of closest approach. Such stopping times are extracted from the TDHF calculations [3] and are indicated in Table 1 as a function of the bombarding energies. One can see that larger is the energy shorter is the stopping time.

E_{lab} (MeV)	t_s (10^{-22} s.)
500	4.9
550	4.0
600	3.4
714	3,0
800	2.5
1000	2.1

Table 1. Stopping times t_s as a function of the bombarding energy. [3]

We have made calculations using the "window formula" [2] and several choices for a conservative force. If s is the separation distance between the surfaces of the interacting nuclei the equation to be solved is :

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$$\mu \frac{d^2 s}{dt^2} = - 2N(s) \frac{ds}{dt} - \frac{dV}{ds} \tag{1}$$

where μ is the reduced mass, $N(s)$ is the proximity flux [4] and $V(s)$ the interaction potential. Four different choices have been made for $V(s)$:

1. Pure Coulomb potential for overlapping charge distributions using the formula of Bondorf et al. [5].
2. Coulomb (Bondorf) + nuclear potential of Wilczyński and Siwek-Wilczyńska [6].
3. Coulomb (Bondorf) + standard proximity potential [7].
4. Coulomb (Bondorf) + modified proximity potential of Randrup [8].

Fig. 1 shows the various potentials as a function of the separation distance between nuclear centres $R = R_1 + R_2 + s$ (R_i - nuclear radii). The standard proximity potential has a very shallow pocket at $s \approx 0$, about 2 MeV deep with respect to the barrier. In the Siwek-Wilczyński potential the pocket at $s \sim -1.6$ fm is somewhat deeper, 6 MeV below the barrier. The modified proximity potential has a broad barrier beyond which it decreases linearly towards the centre.

Fig. 2 shows the surfaces separation s as a function of time in units of 10^{-22} s. at two bombarding energies E_{lab} = 500 MeV and E_{lab} = 1200 MeV for each potential. The origin $t = 0$ corresponds to $s = 3.2$ fm , i.e. the distance at which the friction starts to act [4] . One can see that in the considered energy range none of these potentials gives the behaviour observed in TDHF calculations. The friction by itself is not the only factor to stop the projectile and the stopping time is very sensitive to the non-conservative force. For potentials which stop the projectile the stopping time is comparable with but somewhat longer than that of Table 1. For the Siwek-Wilczyński and the standard proximity potentials it decreases with the energy, like in TDHF calculations, and the values of t_s given by the standard proximity potential are nearest to the TDHF results (5×10^{-22} s for E_{lab} = 500 MeV , 3×10^{-22} s for E_{lab} = 800 MeV and 2.8×10^{-22} s for E_{lab} = 1000 MeV). But after the instant of closest approach in the standard proximity potential the projectile gets captured in the pocket at low energies $\sim$500 MeV and the fragments separate at high energies. The low energy capture at 500 MeV is more reminiscent of the situation found for a lighter pair $^{86}Kr + ^{139}La$ at $E_{lab} = 410$ MeV [1]. On one hand this result is related to the existence of a shallow pocket, the presence of which depends on the choice of the Coulomb interaction. On the other hand it is due to the "window formula" friction which is too strong to allow the separation of the fragments even if there is a shallow pocket. The strong effect of friction given by the "window formula" was also discussed in Ref. [9] for much lighter pairs. For the Siwek-Wilczyński potential it produces a similar effect, the projectile being captured in the pocket for the whole range of bombarding energies between 500 MeV and 1200 MeV . The modified proximity potential is so deep inside the barrier that the projectile gets captured near the centre at all energies.

In conclusion this study suggests that the true nucleus-nucleus interaction might be time and/or energy dependent. At lower energies it might have a hard core which stops the projectile and which crumbles at high energies. In the TDHF calculations of Ref. [10] it is shown that at the beginning of the collision the single particle energies exhibit some stiffness which persists for a while. This is consistent with the sudden approximation on which the standard proximity potential is based. Our calculations suggest that such a stiffness would last for a shorter time at larger bombarding energies leading to a potential shape closer to the modified proximity potential.

We would like to thank the authors of Ref. [1] for discussions of their TDHF results and for providing information about the stopping times.

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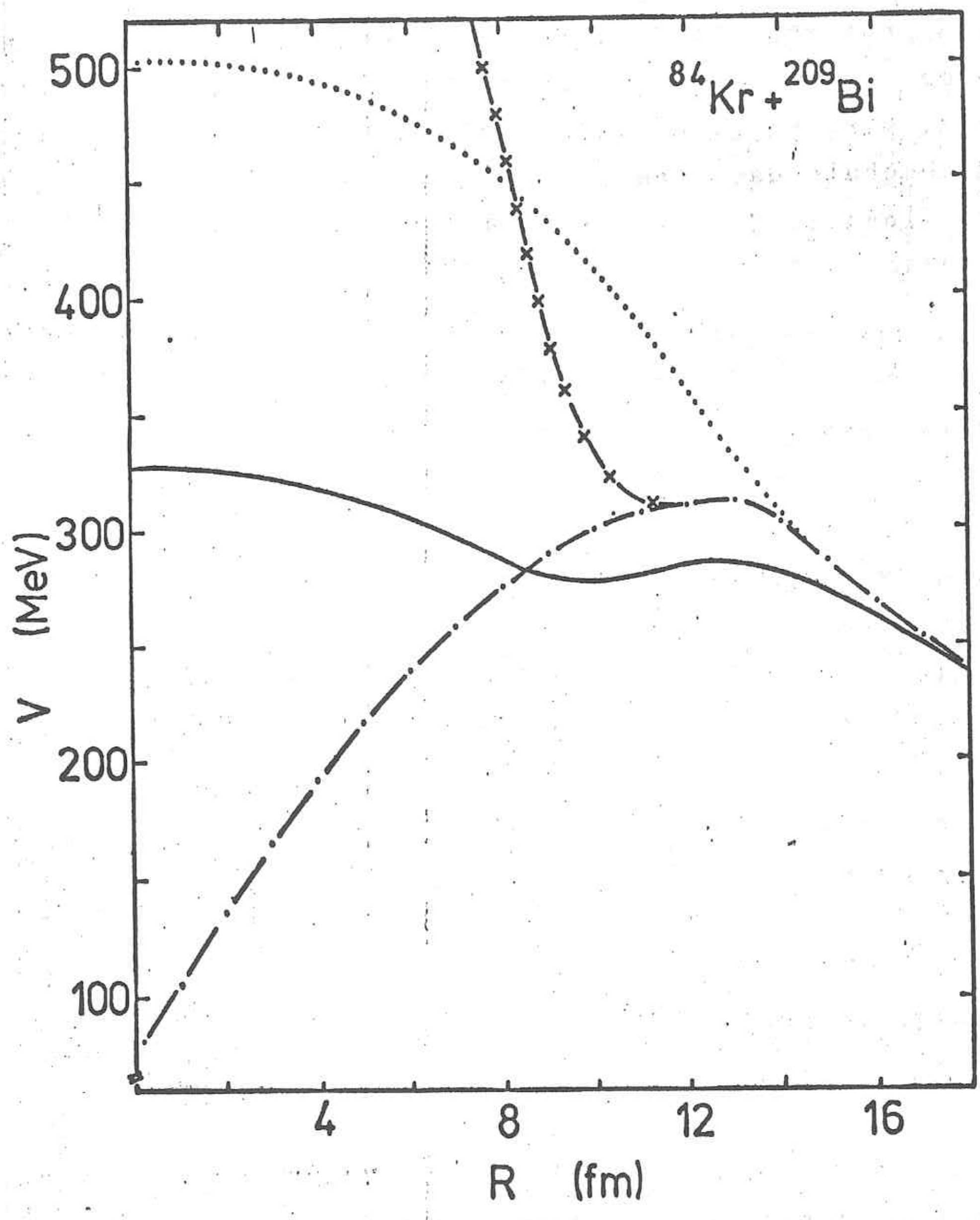
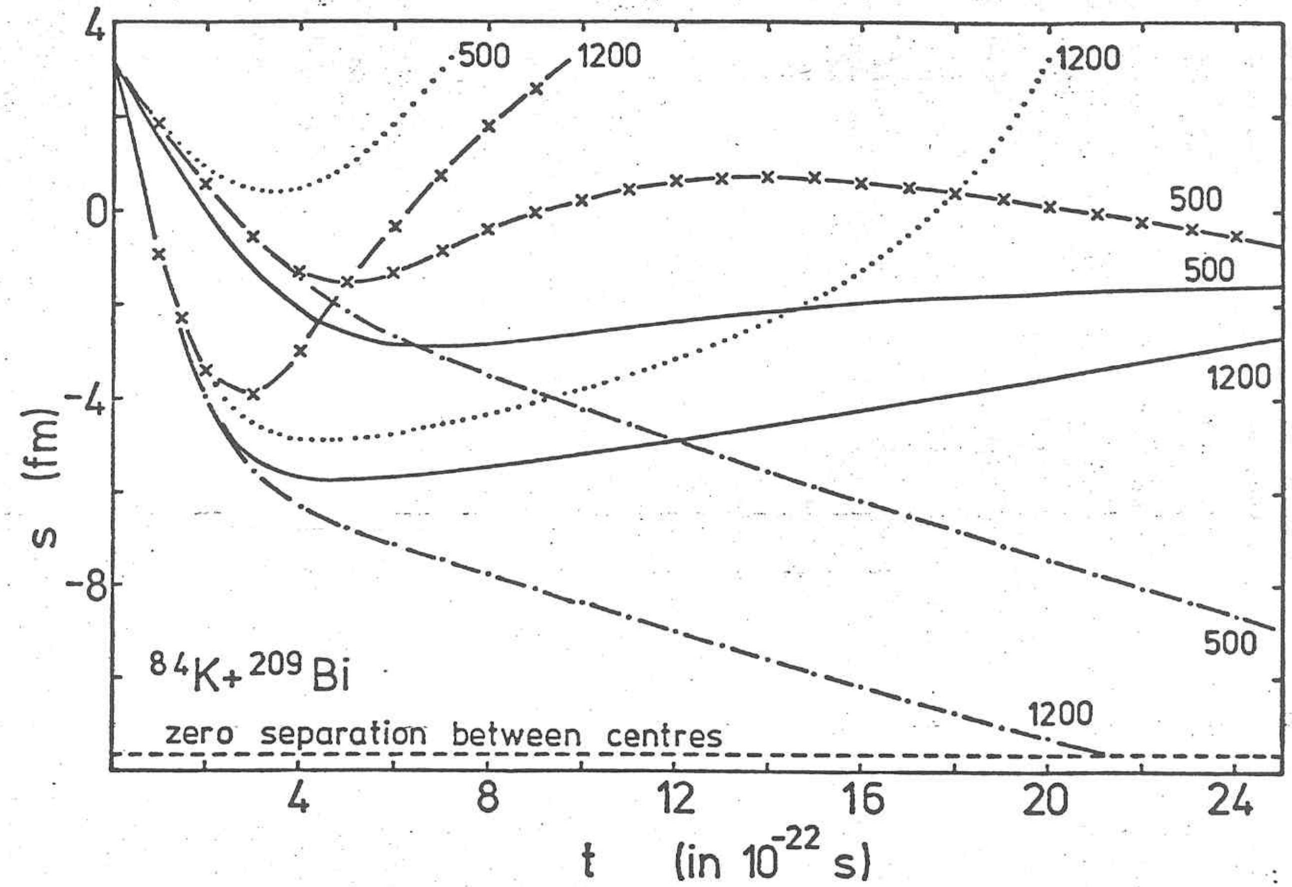
FIG. 1



Four different choices for the interaction potential of $^{84}Kr + ^{209}Bi$ as a function of the separation distance R between nuclear centres : (······) - pure Coulomb (Bondord), (———) - Siwek-Wilczyńska and Wilczyński + Coulomb, (-·-·-) - modified proximity + Coulomb, (-×-×-) - standard proximity + Coulomb.

FIG. 2



Trajectories for $^{84}Kr + {}^{209}Bi$ at E_{lab} = 500 MeV and E_{lab} = 1200 MeV for the corresponding potentials of Fig. 1 (same legend). Here s is the separation distance between nuclear surfaces $s = R - R_1 - R_2$.