

Momentum Conservation in Binary Reactions

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In the IAEA Nuclear Data Section, we recently had occasion to re-examine the old topic of neutron source reactions, such as $D(d,n)^3\text{He}$. As part of this work, I programmed the formulae from page 26 of the GROUPE manual, Chapter VIII of Los Alamos report LA-12740-M. I had to make some modest interpolation of the description there to allow the treatment of an incident particle other than a neutron. For example, I interpret the quantity A as the target mass, relative to the incident particle mass, whether or not the incident particle is a neutron.

Appendix A contains a listing of a short test program that computes spectra from the kinematic formulae in the manual for zero-degree emission. The most interesting result for the present purposes is that I added coding to check of the answers and, at first, the answers failed this test. The code first calculates the energy of the recoil nucleus, in this case ^3He , by conservation of energy, and then it checks the results for momentum conservation. With the original formulae, the result does not quite conserve momentum. After a small amount of experimentation, I found that momentum and energy are conserved if I replace the "target" mass with a mass computed from the total mass of the products (ejectile + recoil) minus the mass of the projectile. This differs from the exact target mass by the Q of the reaction (expressed in AMU). With this change to the formulae, momentum is now conserved.

In Appendix B is listed the results of running the code with 6-MeV deuterons incident. For this test, the code was compiled with REAL=64 and executed on the NDS AlphaServer 2100. The measure of momentum conservation is the variable "forbal" which changes from $3.524793231104439\text{E-}4$ with the uncorrected mass to $-9.769962616701378\text{E-}15$ with the Q -subtracted mass. Thus, it appears that the manual, at least, needs a small correction here. It is currently unclear what, if any, changes may actually be required in GROUPE.

Appendix A. Test Program SPEC4

```

program spec4
c   test momentum conservation effects in connection
c   with binary reaction kinematics, as represented in
c   formulae in the njoy/grouptr manual, eqs. (75-77).
c
c   set constants for D(d,n)He3 reaction, with energies
c   in mev and masses in amu.
c
c   q=3.26892
c   deuteron mass   (particle 1 = projectile)
c   xm1=2.01410
c   helium mass     (particle 2 = recoil)
c   xm2=3.01603
c   neutron mass    (particle 3 = ejectile)
c   xm3=1.00866
c   deuteron mass   (particle 4 = target)
c   xm4=2.01410
c   istart=1
c
c   read in the deuteron energy (in MeV)
c   write (*,*) ' '
c   write (*,*) ' enter e'
c   read (*,*) e1
c
c   ejectile is emitted in forward direction in lab.
c   omega=1.
c
c   calculate ejectile energy in lab.
c   50 continue
c   a=xm4/xm1
c   aprime=xm3/xm1
c   fac1=sqrt(a*(a+1.-aprime)/aprime)
c   fac2=sqrt(1.-(a+1.)*(-q)/(a*e1))
c   r=fac1*fac2
c   solve eq. (76) for eprime
c   eprime=(omega*2.*r+1.+r**2)*aprime*e1/(1.+a)**2
c
c   print results
c   write (*,*) ' '
c   write (*,*) ' eprime =', eprime
c
c   check results
c   e3=e1+q-eprime
c   p2=sqrt(2.*xm2*e2)
c   p1=sqrt(2.*xm1*e1)
c   p3=sqrt(2.*xm3*eprime)
c   recoil must be emitted in either the forward or
c   backward directions in the lab.
c   forbal=p1-(p3+p2)
c   bakbal=p1-(p3-p2)
c   write (*,*) ' '
c   write (*,*) ' forbal,bakbal =', forbal,bakbal

```

```
c  
c   diagnose result  
   if (istart.eq.0) go to 100  
   istart=0  
  
c  
c   compute target mass from other three  
   write (*,*) ' '  
   write (*,*) ' old target mass =', xm4  
   xm4=xm2+xm3-xm1  
   write (*,*) ' '  
   write (*,*) ' new target mass =', xm4  
100 go to 50  
   continue  
   stop  
   end
```

Appendix B. Result of test run with SPEC4

```
<IAEAND> $ run spec4  
  
enter e1  
6  
  
eprime = 9.20805448330349  
forbal,bakbal = 3.524793231104439E-004 1.21220139506198  
  
old target mass = 2.01410000000000  
new target mass = 2.01059000000000  
  
eprime = 9.20798015221335  
forbal,bakbal = -9.769962616701378E-015 1.21258866601987
```