EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Clarification to the ISOLDE and Neutron Time-of-Flight Committee

IS530: Properties of low-lying intruder states in ^{34}Al and ^{34}Si sequentially populated in beta-decay of ^{34}Mg

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Abstract

Following the analysis of the Addendum CERN-INTC-2014-027 / INTC-P-314-ADD-1, the INTC requested a clarification in the minutes of the 46th meeting (CERN-INTC-2014-037 – INTC-046) before recommending additional shifts. The present letter addresses the three main topics suggested by the INTC: i) a more elaborated scientific motivation for the measurement of the branching ratio in ^{34}Si; ii) a detailed explanation of the expected gain in statistics; iii) what could be achieved using only the available shifts.

Requested shifts: 15 shifts, (into 1 run over 1 year)

i) Motivation

Deformation and shape coexistence have been an important topic in the nuclear structure field for more than five decades now [1]. Since then an increasing flow of experimental evidences proved the robustness of the magic shell closures around the stability line, and revealed their collapse and/or the development of new ones while venturing into the exotic regions of the nuclear chart. A particular manifestation of such phenomena in the 'exotic nuclei ocean' is the occurrence of 'islands of inversion'. It was shown that for nuclei with N=20, 28, 40 (and their vicinity) while changing Z for a given N, nuclear structure properties no longer obey the 'closed neutron shell' predictions. These experimental findings were gradually understood and theoretically explained to be the consequence of the presence of multipatricle - multihole configurations in the ground states of nuclei such as ^{32}Mg, ^{42}Si, ^{64}Cr [2,3]. It turns out that for particular (Z, N) values the correlation energy in these intruder configurations (quadrupole and pairing energy gain mainly) is larger than the energy cost to create the intruder configuration, thus leading to ground-states in both even-even and odd-mass nuclei becoming strongly correlated states, subsequently gaining extra binding [4]. The same np-nh configurations may give rise to collective excitations, where low excitation energy 0+ states may occur together with large values of B(E2) inside the excited band. These are sometimes found right along side with low lying states where the closed shell configuration is dominant, fact rendered possible by the small mixing amplitudes of different configurations.

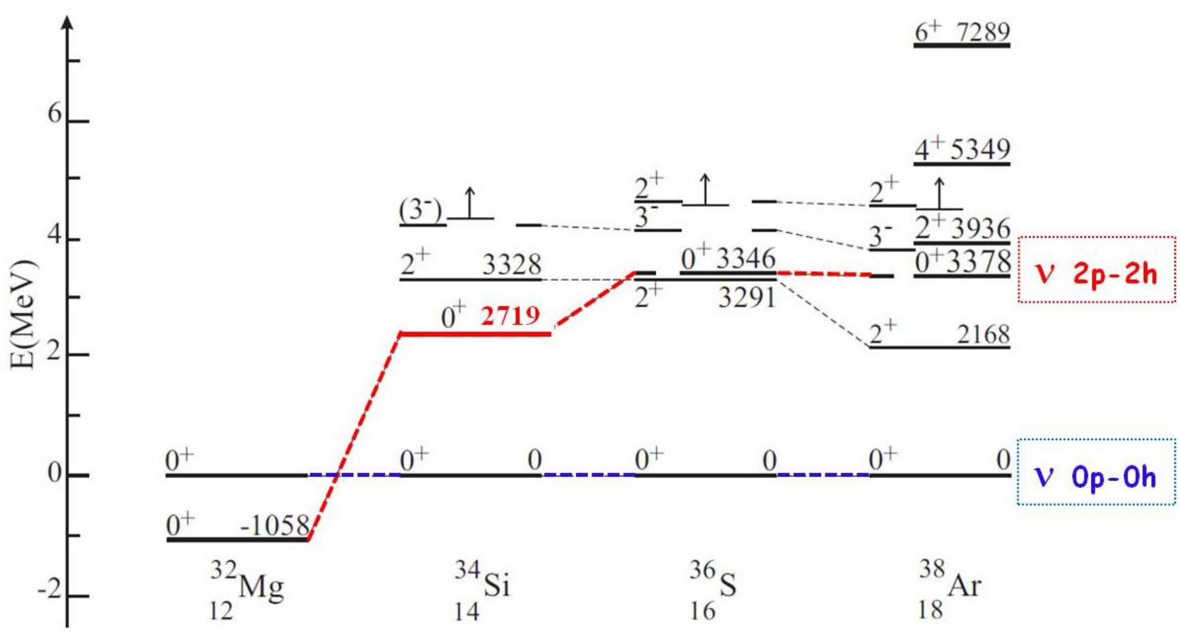

Figure 1 Evolution of the intruder (dominated) 0+ states with respect to the normal ones along the N=20 line

The oldest of the above islands of inversion is the one at N=20 centered on ^{32}Mg, but its boundaries are still an opened question to both experiment and theory. Also, the smooth transition from the closed-shell ground-state of the doubly-magic ^{40}Ca, through the spherical ^{36}S down to the intruder-dominated deformed g.s. of ^{32}Mg inside the island of inversion is not yet fully understood – Fig.1. Only recently the normal configuration 0+ in ^{32}Mg [5] and the intruder deformed one in ^{34}Si [6] were placed in the above picture, while their complete experimental description is still waited.

In order to extract the mixing amplitudes of the normal and intruder configurations that describe the $0_{1,2}$+ states of interest one can make use of the simple two level mixing model, as shown in [7, 6]. The key ingredient for such a calculation is the ratio between the B(E2) values from 2+ to 0_1+ and 0_2+ respectively. Moreover, using the experimental mixing amplitudes in the frame of the same model, the deformation of the intruder configuration can be extracted from the monopole strength ρ^2(E0: 0_2+→ 0_1+).

The experiment that revealed the 0_2+ state in ^{34}Si [6] also measured the half-life of 19.4(7) ns, deducing an electric monopole strength of ρ^2(E0)=13.0(9)x10^{-3}, thus rendering possible the extraction of the experimental mixing amplitudes, once the branching ratio of the 2+ deexcitation to 0_1+ and 0_2+ is known. This quantity was also measured in the same experiment, however with a large error due to low statistics and unquantified uncertainty associated to the complex shape of the background: R(2_1+→ 0_1+/2_1+→ 0_2+)=1380(717). The 52% error on the branching ratio led to a higher one in the determination of the B(E2: 2_1+→ 0_2+)= 61(40) e^2fm^4, using the previously known B(E2: 2_1+→ 0_1+)= 17(7) e^2fm^4 [8]. Consequently, the extracted mixing amplitude: $\cos^2\theta$=22(7) and the deformation parameter $|\beta_2|$=0.28(3) were also affected. More accuracy and higher degree of confidence of experimental data will offer stronger constraints for adjustment of interaction used in shell-model calculations that reproduce well the B(E2) values, but deviates in the prediction of mixing and deformation [6].

ii) Experimental set-up optimization for improvement of the statistics

The run of the IS530 experiment scheduled in September 2012 was successful and many new results have been obtained as described in the submitted Status Report INTC-2014-026 / INTC-SR-037. However, one of the goals of the experiment, namely the measurement of branching ratio of the 2^+ state transitions toward the two lower 0^+ states in ^{34}Si has not been achieved, thus becoming the main goal of the Addendum INTC-2014-027 / INTC-P-314-ADD-1. The statistics obtained for the transition $2^+ \rightarrow 0_2^+$ in ^{34}Si expected at 607±3 keV [6] is several times lower than our estimate in the original proposal, being hardly visible out of background. Taking advantage of the larger lifetime measured for ^{34}Mg and various improvements of the experimental set-up, an increase of one order of magnitude is expected in the statistics, as detailed in the paragraphs below.

a) The maximum yield of ^{34}Mg measured during the IS530 run in September 2012 was 140 ions/μC, as mentioned in database. However the yield was fluctuating with mean value at 75% from maximum over an actual measuring time of about 6 UTs. In the remaining 9 UTs from the total of 15 used UTs, the yield was very low or the beam was stopped for various technical problems (such as beam gate malfunctioning). Working with the already commissioned set-up of the new permanent IDS we expect to take full benefit of the requested 15 shifts (7 UTs available and 8 UTs requested in addition) at the better mean yield (75% of the maximum) achieved during the previous run. Assuming that we will work with an average yield similar to the one measured in the above 6 UTs, and if we account for a 10% effective acquisition time loss (due to stop/start of the acquisition, nitrogen refilling of the detectors, minor electronics adjustments etc.) we expect to double the previous statistics over 13.5 UTs.

b) Based on previous estimate of the ^{34}Mg half-life of 20±10 ms, a beam gate of 50 ms - opened shortly after the proton bunch arrival - has been used. The offline analysis revealed that the half-life is in fact three times larger: 63±1 ms. Therefore the increase of gate duration to 150-200 ms is expected to increase the number of implanted ions per pulse by a factor of 2.

c) During the run in September 2012 the gamma detection was assured by 3 GeHP clover detectors, one coaxial Ge detector (all visible in Figure 2) and 5 $LaBr_3$ detectors at forward angles. The coaxial detector was very noisy and it provided no contribution to the total gamma efficiency; it will be replaced in the new IDS setup by a 4th clover. In our previous run we measured an efficiency of 1% @ 1 MeV for each clover, so the 4th clover will bring an increase of 33% in the GeHP total efficiency.

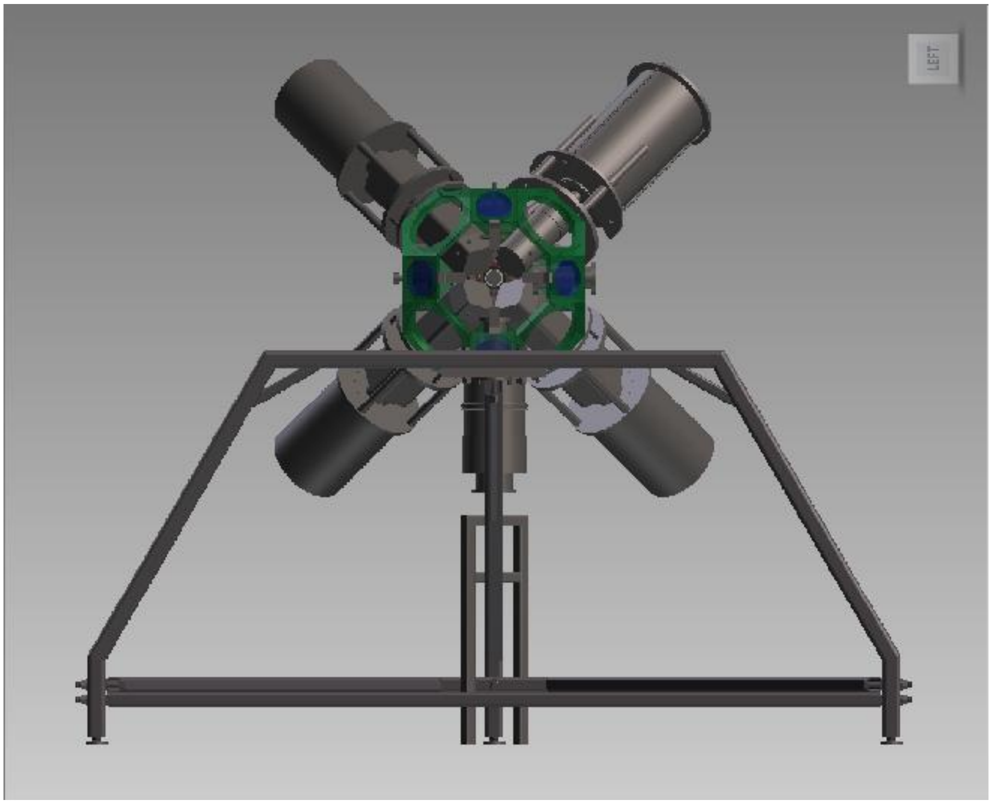

Figure 2 Zero degree perspective (CAD) of the initial IDS setup

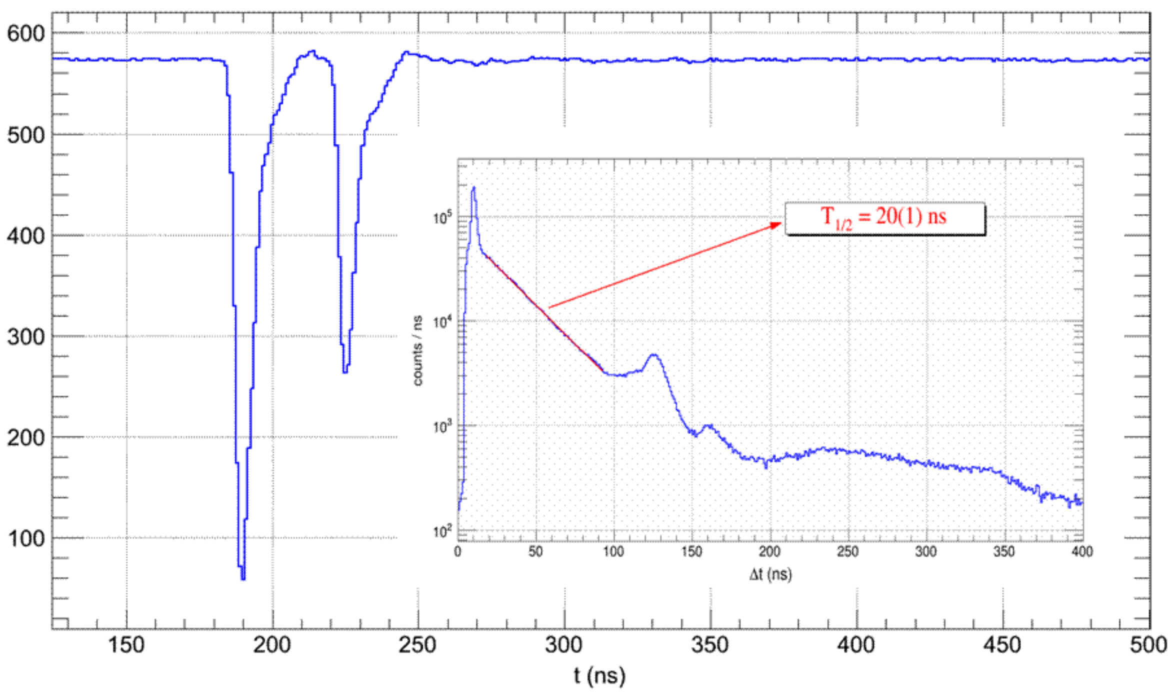

Figure 3 Digitized trace from the plastic detector for a 'double hit' type of event. The inset is the time spectrum resulting from the analysis of such traces, leading to a 20(1) ns half-life for the 0_2+ in ^{34}Si

In the original proposal, the LaBr3 detectors at zero degrees were useful for the detection of the 607 keV gamma line in ^{34}Si ($2_1+\rightarrow 0_2+$), because as we saw in the experiment at GANIL [6], the main background and contaminant of this peak are the 596 keV and 608 keV lines from ^{74}Ge(n,n') inelastic scattering. In our experiment the neutrons are coming from the β-n and β-2n decay channels (^{34}Mg, ^{34}Al), rendering the contaminant gammas coincident with the beta electrons that we detect. However, our fast timing method applied to the plastic scintillator used as beta detector, by means of a fast digitizer, was very selective. It allowed us to remove the gamma contaminants originating in the (n,n') – as shown in figure 4 – by gating on the 'plastic double hit' type of events – see figure 3. In these events, the first hit is generated by the beta electron (from the β-decay of ^{34}Al), while the second hit corresponds to either e- or e+ (or both) emitted in the IPF branch of the E0 transition in ^{34}Si ($0_2+\rightarrow 0_1+$). The inset of fig.3 shows a fit on the time spectrum resulted from the time difference between the two hits, and the resulting half-life of 20(2) ns confirms that this is an appropriate method to gate on the E0 deexcitation in ^{34}Si. This justifies the replacement of the 5 LaBr3 at 0 degrees by a 5th clover detector – it will be about 3 cm closer to the implantation point than the other 4 detectors, thus leading to an efficiency of ~2% @ 1 MeV. Therefore the resulting gain for the total GeHP gamma efficiency during the next run will be of a factor 2.

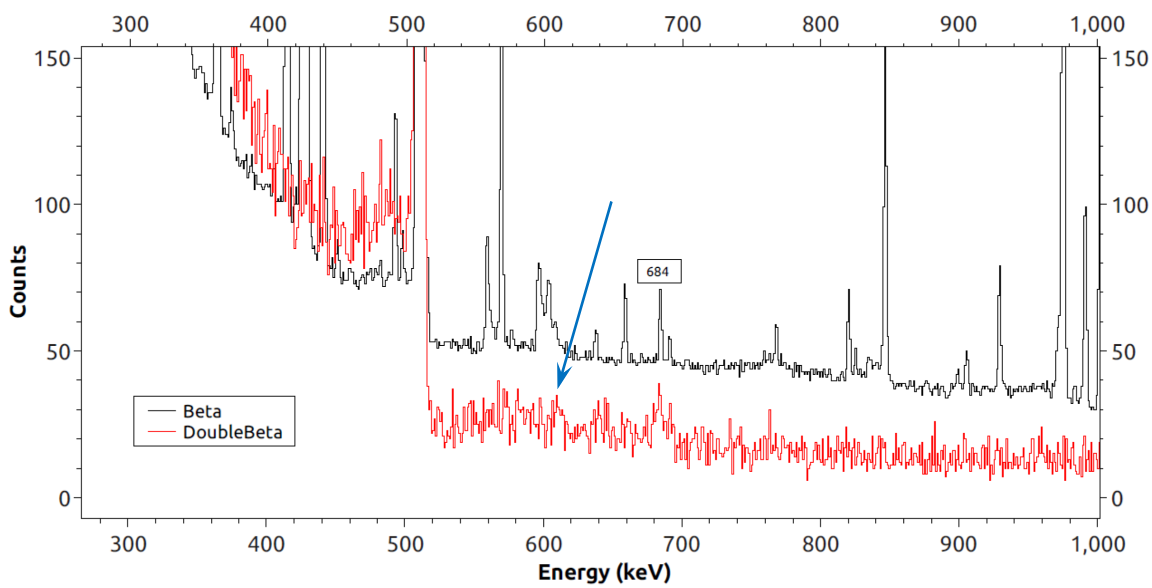

Figure 4 Beta-gated gamma spectrum in black - scaled by a factor of 0.038 for visualisation purposes. The spectrum in red is conditioned by the double hit events in the beta detector with a time difference between the two hits in the range of [16, 205] ns (see Fig. 3). The peak of interest at 607(3) keV is marked by an arrow.

d) The fast plastic scintillator used as beta detector was designed to assure a geometrical coverage of ~95% around the implantation point. At the same time the thickness was kept at only 3-4 mm in order to reduce the absorption of low energy gamma rays that may connect the 4– and 1+ states in ^{34}Al. This lead to a complex form of the detector and, also to electronic noise that imposed a rather high threshold, thus leading to a beta efficiency of about energy 80% for high beta transitions decreasing to about 70% for beta transition of 2 MeV. The low energy gamma rays are no longer of interest because after the first run of the experiment it has been clearly shown that the 4 – state in ^{34}Al is not populated in the decay of ^{34}Mg, and therefore we can improve the beta efficiency using a thicker rectangular beta detector (with just one channel for the tape passage and one channel for ions passage towards the tape) read simultaneously by 2 photomultipliers. Thus we expect an increase of the beta efficiency close to the limit of geometrical coverage mentioned above. Moreover, the technique of identification of double hits in beta detectors described above, when applied simultaneously on the two waveforms from the two photomultipliers will most likely eliminate the spurious maximum observed in left side of spectrum in the inset of Figure 3. In this case, the condition of having the distance between hits larger than 16 ns will be relaxed to about 6-7 ns, recovering about 25% of E0 transition that are lost (due to the half-life of 20 ns). Therefore the improvements brought to the beta detection may further increase by a factor of 1.5 the statistic in the gamma spectrum gated by the beta-E0 events.

To summarize, by joining the gain factors detailed above:

- a factor 2 in the total number of implanted ^{34}Mg nuclei (from the beam time),
- a factor 2 from the adaptation of the beam gate to the 'new' ^{34}Mg half-life,
- the doubling of the total gamma efficiency,
- a 1.5 factor from the improvements brought to the plastic scintillator,

we expect an overall improvement by a factor of about 10 in the number of detected photons of 607(3) keV that would allow the measurement of the branching ratio $R(2_1+\rightarrow 0_1+/2_1+\rightarrow 0_2+)$ in ^{34}Si.

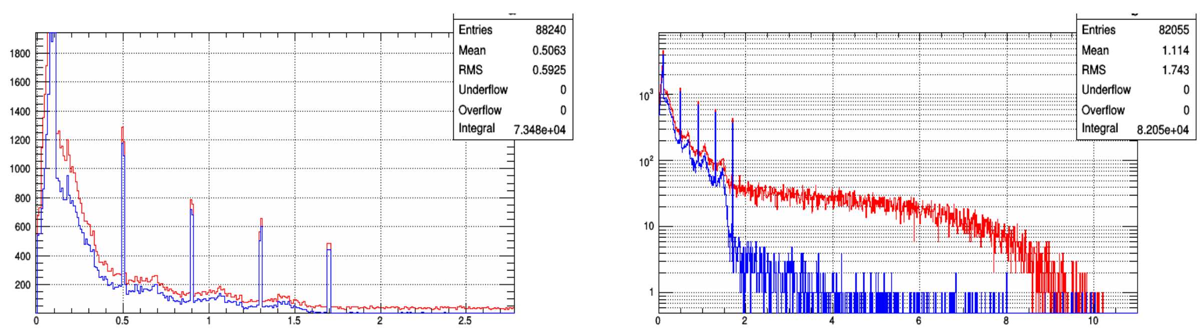

Figure 5 GEANT4 spectra of two clover crystals: *red* – ungated spectra; *blue* – spectra conditioned by zero energy deposited in the plastic veto in front of the clover detector

A further improvement of the setup that we plan for the next run concerns the peak to noise ratio. The goal is to reduce the background induced in the Ge detectors by the beta electrons entering the crystal. In order to achieve that, we are planning to place a square 5 mm thick plastic scintillator in front of each clover detector that will be used as a particle veto for the gamma spectra (figure 5). The choice of thickness is the result of GEANT4 simulations that we performed in order to determine the optimum value – high efficiency to detect beta electrons and low probability of interaction with photons above a few hundred keV and. The simulated source in figure 5 is a beta-gamma source with photons of 500, 900, 1300 and 1700 keV each emitted in coincidence with electrons with energies up to 15 MeV. Appling the anticoincidence condition (veto) with plastic detector, the photopeak efficiency decreases ~5% in the region of interest (607 keV) while background due to electrons is strongly suppressed. The remaining background is dependent on the presence of higher energy gammas.

iii) Counting estimates using the presently available shifts

In the first run we estimate that we detected 15 gammas in the 607 keV peak after the delayed double-hit conditioning (see Figure 3 - inset) over 6 UT of effective beam time. In the optimistic assumption that we will have same effective beam time of 6 UT out of the 7 available shifts, with all the improvements mentioned at points b)-d) above, we expect a factor of 5, that is 75 counts in gamma peak of interest.

However, the above proposed set-up imposes several modifications to the current IDS set-up:

- Replacing interaction chamber inside gamma detectors support structure with the one used the first run;
- Addition of one clover detector at zero degree;
- Addition of plastic veto detector in front of each clover;
- Use of high efficiency beta detector with double PMT readout;
- Addition of one fast digitizer for beta detector waveform acquisition.

Some of these points require precise tuning (mainly in beam beta-gamma timing adjustments) and debugging of errors that are always observed in the first UTs of the experiments. Therefore, even excluding a technical failure, we consider that is realistic to suppose an effective total acquisition time at desired count-rate of only 3-4 UTs, meaning that expected gain factor will only 2.5 representing some 40 events in the peak of interest. This might be not enough to achieve the main goal of the addendum.

Summary of requested shifts:

isotope	yield (/uC)	target – ion source	Shifts (8h)
^{34}Mg	150	UCx	15

Total shifts: 15

References:

[1] K.Heyde and J.L.Wood, Rev.Mod.Phys. 83 (2011) 1467

[2] E.Caurier et al., Rev.Mod.Phys. 77 (2005) 427

[3] O.Sorlin et M.G.Porquet, Prog.Part.Nucl.Phys. 61 (2008) 602

[4] N.A.Smirnova et al., Phys.Rev.C 86 (2012) 034314

[5] K.Wimmer et al., Phys.Rev.Lett 105 (2010) 252501

[6] F.Rotaru et al., Phys.Rev.Lett. 109 (2012) 092503

[7] C.Force et al., Phys.Rev.Lett. 105 (2010) 102501

[8] R.W.Ibbotson et al., Phys.Rev.Lett. 80 (1998) 2081