Anomalous Strong Interaction in pionic Mg

Citation for published version (APA):
Taal, A., Achard van Enschut, d', J. F. M., Berkhout, J. B. R., Duinker, W., Eijk, van, C. W. E., Hesselink, W. H. A., Hoek, van den, P. J., Ketel, T. J., Koch, J. H., Konijn, J., Laat, de, C. T. A. M., Lourens, W., Middelkoop, van, G., Poeser, W., Prins, T., & Wapstra, A. H. (1985). Anomalous Strong Interaction in pionic Mg. *Physics Letters B*, *156*(5-6), 296-300. https://doi.org/10.1016/0370-2693(85)91612-0

DOI:
10.1016/0370-2693(85)91612-0

Document status and date:
Published: 01/01/1985

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 17. Nov. 2023

ANOMALOUS STRONG INTERACTION IN PIONIC Mg

A. TAAL [a], J.F.M. D'ACHARD VAN ENSCHUT [b], J.B.R. BERKHOUT [c], W. DUINKER [a],
C.W.E. VAN EIJK [b], W.H.A. HESSELINK [c], P.J. VAN DEN HOEK [d], T.J. KETEL [c],
J.H. KOCH [a], J. KONIJN [a], C.T.A.M. DE LAAT [a], W. LOURENS [b], G. VAN MIDDELKOOP [a],
W. POESER [a], T. PRINS [a] and A.H. WAPSTRA [a]

[a] *NIKHEF-K, Amsterdam, The Netherlands*
[b] *Technische Hogeschool, Delft, The Netherlands*
[c] *Vrije Universiteit, Amsterdam, The Netherlands*
[d] *Rijksuniversiteit Groningen, Groningen, The Netherlands*

Received 14 February 1985

The pionic 2p → 1s transition has been observed in Mg. For the strong interaction monopole shift a value has been measured of $\epsilon_0(1s) = -81.6 \pm 0.6$ keV with respect to the point Coulomb energy, in agreement with standard optical potential predictions. The observed strong interaction absorption width is $\Gamma_0(1s) = 17.2 \pm 1.6$ keV, which is about a factor of 1.5 smaller than expected from presently available models. This measurement confirms the trend of "anomalously" small strong interaction widths for deeply bound pionic states already observed in heavier elements.

The measurement reported in this paper is an extension of a series of experiments designed to study strong interaction shifts and widths of deeply bound states of pionic atoms. Observed ϵ_0 and Γ_0 of 3d levels for a variety of heavy nuclei deviate strongly from standard optical potential predictions being typically a factor of two smaller than predicted [1–8]. Similar observations have been made for the absorption widths of other deeply bound pionic states: ^{110}Pd(3p) [9], ^{75}As(2p) [10], ^{23}Na(1s) [11]. The general structure of the optical potential employed in pionic atoms incorporates two main terms: a repulsive s-wave part and an attractive non-local p-wave part. In order to localize from which part the anomaly comes the most obvious places to look for are deeply bound pionic 1s orbits, where the s-wave repulsion is dominating the pion–nucleus interaction. In the present paper results are reported of measurements on the pionic 1s orbit in Mg performed at the pion facility of NIKHEF-K at Amsterdam. The experimental set-up comprised a conventional beam telescope, incorporating four plastic scintillation counters and a Čerenkov counter. The pion channel was tuned for 140 MeV/c particles. Approximately 2×10^4 π^-/s were stopped in a high-purity metallic target of natural Mg. The target thickness was 2.33 g/cm^2. The pionic X-rays were detected by two large volume (n-type) Ge detectors.

In studying weak and broadened pionic transitions it is essential to increase the peak to background ratio. This was done in the following way:

(i) The Ge-detectors were surrounded by Compton-suppression shields with an effective suppression-factor of about 5.5.

(ii) The detectors were placed at a distance of about 60 cm from the Mg target, which allowed us to reduce the neutron-induced background by time-of-flight discrimination in the off-line analysis.

(iii) Care was taken to prevent pile-up in the pion-stop signal in a time interval of 150 ns either before or after any pion stop to avoid ambiguities in the recording of the time spectra.

(iv) Pulse pile-up rejectors (Canberra 1468) in the circuit of the analog signal to the ADCs were used to minimize spectrum background and photo-peak-shape detoriation due to pile-up.

Energies were recorded from 2.5 MeV down to

0370-2693/85/$ 03.30

about 20 keV (the nf → 3d pionic X-ray series, where self-absorption is rather large) in 8192 channels. For the energy calibration of the detector we used several well-established nuclear gamma-ray transitions produced simultaneously in the target nucleus. For the detector response function standard sources were used. We determined a gaussian line shape, tailing of the peak on both sides and a difference in the magnitude of the background on the right- and left-hand side of the peak (usually some 0.5% of the peak height) by introducing a step function. In the inset of fig. 1 the 320 keV line from a ^{51}Cr source and the line shape used in the analysis are shown. The strong interaction broadening is accounted for by folding this fixed response function with a lorentzian line shape. The inclusion of the step function is of vital importance for the analysis, especially in the case of Mg, where an intense nuclear gamma-ray transition (^{21}Ne) is situated just above the energy region of the pionic 2p → 1s transition. The prompt pionic Mg X-ray spectrum is shown in fig. 1. This spectrum is the result of the application of a prompt time window in the two dimensional time–energy spectrum. In fig. 2 the fit to the experimental points is shown in the energy region of interest. Clearly shown is the step function for the background.

In evaluating the intensity balance of the pionic 2p level in Mg, we used a large time window to allow for shifts in the timing as a function of gamma energy. A correction for the presence of a prompt 73.97 keV gamma-ray transition (next to 3d → 2p 74.4 pionic X-ray) from the ^{24}Mg(π,2nγ)^{22}Na reaction, has been applied for. From the intensity of the subsequent 583 keV (τ = 352 ± 8 ns) transition, the intensity of the

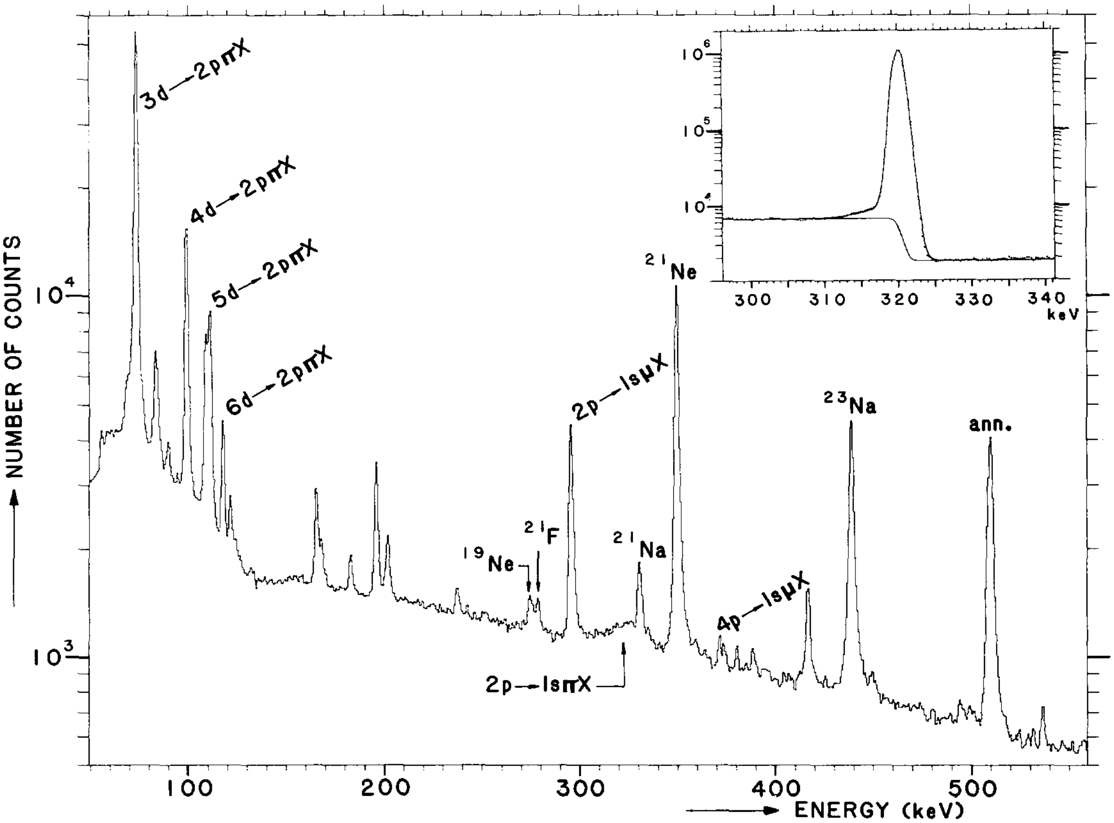

Fig. 1. The measured pionic X-ray spectrum of Mg, resulting from the application of a prompt time window in the two-dimensional time–energy spectrum. The inset shows the Compton-suppressed detector response to the 320.08 keV gamma-ray transition in ^{51}Cr. The drawn line is the fit to the experimental points. Clearly shown is the used step function of the background. The height of the step is a constant fraction of the peak area.

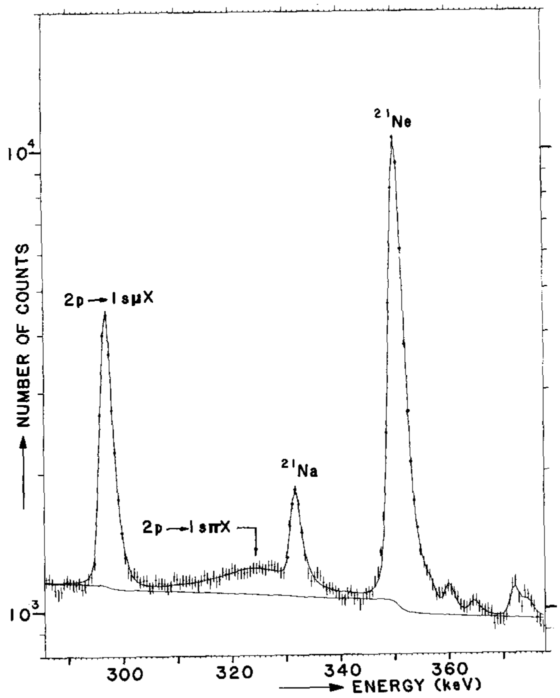

Fig. 2. Part of the pionic X-ray spectrum shown in fig. 1, showing the energy region of the pionic 2p → 1s region. The fit to the experimental points is represented by the drawn line. The strong transitions at 296 keV, 331 keV and 350 keV are the muonic 2p → 1s X-ray, ^{21}Na and ^{21}Ne nuclear gamma-rays, respectively.

73.79 keV gamma-ray was determined to be 34% of the measured intensity of the complex at 74 keV. The results of the pionic X-ray intensities are given in table 1. The experimental energies and intensities are in rather good agreement with the calculated values, obtained by using the pionic X-ray cascade code STARKEF, which uses the observed transition energies and level widths as input.

The results of our analysis of the strong interaction shift and width is $\epsilon_0(1s) = -81.6 \pm 0.6$ keV and $\Gamma_0(1s) = 17.2 \pm 1.6$ keV. These values are compared to the predictions of the standard optical potentials in table 2. From the intensity balance follows $\Gamma_0(2p) = 69 \pm 9$ eV, using the value of $\Gamma_{\mathrm{rad}}(2p) = 1.407$ eV for the electromagnetic radiative width. This value compares well with calculations and with the result of Beer et al. [13] given in table 2. Conversely, accepting their experimental width of 74.9 ± 1.7 eV and the intensity balance the relative 2p → 1s transition intensity becomes $I(2p \to 1s) = (2.56 \pm 0.15)\%$. Use of this value as an extra condition in the fitting procedure results in $\Gamma_0(1s) = 14.3 \pm 1.9$ keV for the absorption width, a result that is even further reduced with respect to the theoretical values and our value obtained by a free fit of the data.

At the conference PANIC in Heidelberg, where a preliminary analysis of the present work was reported [17], an account was also given on pionic Mg measurements performed at TRIUMF [18]. Their reported absorption width is in agreement with theory. Provided, however, that the data from TRIUMF are analysed

Table 1
Observed pionic X-ray in Mg.

Transition	E_γ (keV)	I_γ (rel. int.)	I_γ (calcul.)
4f → 3d	25.9	80 ± 9	82.6
5f → 3d	37.8	10 ± 3	14.2
3d → 2p	74.430 ± 0.008	100 ± 7	100 (norm)
4d → 2p	100.302 ± 0.015	21.5 ± 2.2	19
5d → 2p	112.303 ± 0.017	10.1 ± 1.0	10.7
6d → 2p	118.77 ± 0.03	4.4 ± 0.5	5.11
7d → 2p	122.81 ± 0.06	1.3 ± 0.2	1.94
8d → 2p	125.24 ± 0.15	0.5 ± 0.1	0.75
9d → 2p	128.3 ± 0.4	0.2 ± 0.1	0.20
higher transitions → 2p			0.53
Auger transitions → 2p			0.46
2p → 1s	324.4 ± 0.6	2.7 ± 0.3	

Table 2
Strong interaction monopole shifts with respect to the calculated point Coulomb energy and strong interaction monopole widths for the pionic 2p and 1s levels in Mg. The Fermi parameters are obtained from Engfer et al. [12] (c = 3.046 fm and t = 2.3 fm). The value of c actually used in the calculations is obtained by unfolding the finite size of the proton.

Quantity	Level	Experiment	Reference	Theory			
				I a)	II b)	III a)	IV c)
ϵ_0	2p	128.45 ± 0.41 eV	Beer d)	103.6 eV	130.2 eV	91.7 eV	126.0 eV
	1s	−81.6 ± 0.6 keV	this paper	−78.9 keV	−76.7 keV	−78.9 keV	−78.1 keV
Γ_0	2p	74.9 ± 1.7 eV	Beer d)	61.9 eV	74.5 eV	56.5 eV	69.2 eV
		69 ± 9 eV	this paper				
	1s	17.2 ± 1.6 keV e)	this paper	24.2 keV	25.9 keV	24.3 keV	23.0 keV

a) Ref. [14]. b) Ref. [15]. c) Ref. [16]. d) Ref. [13].
e) With the intensity of the 2p → 1s transition fixed (see text) the result would have been Γ_0 = 14.3(19) keV.

similarly to the present ones, they do agree with the present shifts and widths.

A comparison of the experimental results for ϵ_0 and Γ_0 of the 2p and 1s levels with standard optical model calculations (see table 2) shows that none of these parameter sets are able to predict the data of both levels simultaneously. For the 2p level the calculations come close to the data, while only the parameter set of Batty et al. [15] yields good agreement with the SIN results [13] for the 2p level. The present value for ϵ_0(1s) results in a (8.7 ± 1.0)% stronger repulsion (taking into account that the shift due to nuclear finite size is −20.1 keV). All predictions fail badly on Γ_0(1s) for which the experimental value is a factor of 1.5 smaller [‡1]. This most likely is the result of an increased s-wave repulsion in the pion–nucleus interaction, as the non-local p-wave part of the optical potential hardly is of importance in absorption from the 1s orbit. An increased s-wave repulsion [1,6,19] may also be able to explain the anomalously small pionic 3d level absorption widths mentioned above. In this context we recall that for low-energy pion scattering a similar s-wave repulsion has been observed, see refs. [20–23].

The experimentally found s-wave repulsion in the real part of the pion–nucleus interaction has never been explained by theory. So far theoretical efforts by Tauscher and Schneider [24] by introducing higher order terms in the Ericson–Ericson optical potential have not been able to reproduce the results for deeply bound pionic orbits. Parametrization studies [16,19] point in the direction of an increased s-wave repulsion of the order of 30 to 40 MeV.

As pion absorption on nuclei mainly involves two nucleons one may at very short separations have to abandon the conventional description of the nucleus in terms of the nucleonic degrees of freedom. Calculations of this type applied to other processes have been performed by Kisslinger et al. [25,26]. In these calculations the short range of the interaction is then described in terms of six-quark bags. So far this has not been applied to pion absorption in pionic atoms.

This work is part of the research programme of NIKHEF-K at Amsterdam, made possible by financial support from the Foundation for Fundamental Research on Matter (FOM) and the Netherlands Organization for the Advancement of Pure Research (ZWO).

References

[1] J.F.M. d'Achard van Enschut et al., Phys. Lett. 136B (1984) 24.
[2] J. Konijn et al., Nucl. Phys. A236 (1979) 401.
[3] R. Beetz et al., Z. Phys. A286 (1978) 215.
[4] J.H. Koch and F. Scheck, Nucl. Phys. A340 (1980) 221.
[5] C.J. Batty et al., Nucl. Phys. A355 (1981) 383.
[6] J. Konijn et al., Nucl. Phys. A360 (1981) 187.
[7] J.F.M. d'Achard van Enschut et al., Strong interaction effects in pionic ^{208}Pb, preprint NIKHEF-K (1985).

[‡1] In fact this is found too in our preliminary results on pionic Al.

[8] A. Olin et al., contribution Proc. Particles and nuclei, Xth Intern. Conf. PANIC (Heidelberg, July 1984), L9.
[9] M. Leon et al., Phys. Rev. Lett. 37 (1976) 1135.
[10] R. Abela et al., Z. Phys. A282 (1977) 93.
[11] A. Olin et al., Nucl. Phys. A312 (1978) 361.
[12] R. Engfer et al., At. Data Nucl. Data Tables 14 (1974) 509.
[13] W. Beer et al., contribution Proc. Particles and nuclei, Xth Intern. Conf. PANIC (Heidelberg, July 1984), L11.
[14] L. Tauscher, Proc. Intern. Seminar on π-meson–nucleus interactions (Strasbourg, 1971) (CNRS, Strasbourg, 1971) p. 45.
[15] C.J. Batty et al., Nucl. Phys. A402 (1983) 411.
[16] R. Seki, Phys. Rev. C27 (1983) 2799.
[17] J.F.M. d'Achard van Enschut et al., contribution Proc. Particles and nuclei, Xth Intern. Conf. PANIC (Heidelberg, July 1984), L6.
[18] D. Britton et al., contribution Proc. Particles and nuclei, Xth Intern. Conf. PANIC (Heidelberg, July 1984), L8.
[19] J.G.J. Olivier et al., Nucl. Phys. A429 (1984) 477.
[20] S.A. Dytman et al., Phys. Rev. C19 (1979) 971.
[21] B.M. Preedom et al., Phys. Rev. C23 (1981) 1134.
[22] K. Stricker et al., Phys. Rev. C19 (1979) 929.
[23] L. Antonuk et al., Nucl. Phys. A420 (1984) 435.
[24] L. Tauscher and W. Schneider, Z. Phys. 271 (1974) 409.
[25] L.S. Kisslinger, Phys. Lett. 112B (1982) 307.
[26] E.M. Henley, L.S. Kisslinger and G.A. Miller, Phys. Rev. C28 (1983) 1277.