Open access • Journal Article • DOI:10.1088/0305-4616/9/10/005

Pionic Corrections and Multi - Quark Bags — Source link

Piet J. Mulders, Anthony W. Thomas

Published on: 01 Oct 1983 - Journal of Physics G: Nuclear Physics (IOP Publishing)

Topics: Hadron spectroscopy, Meson, Quark, Hadron and Baryon

REF.TH.3443-CERN

PIONIC CORRECTIONS AND MULTIQUARK BAGS

P.J. Mulders
Center for Theoretical Physics, Laboratory for Nuclear Science
Massachusetts Institute of Technology, Cambridge, MA 02139

and

Anthony W. Thomas
CERN -- Geneva

ABSTRACT

We investigate the influence of pionic corrections on multiquark hadrons. After determining the bag parameters from ordinary baryons and mesons, we discuss the implications for six quark configurations.

REF.TH.3443-CERN
15 October 1982

1. - INTRODUCTION

In this paper we wish to investigate the masses of multiquark bag states, including the contribution from the pion field. For the ordinary baryons and mesons these contributions have been shown to amount to 100 MeV or more[1)-5)]. Furthermore, the pion energy provides another mechanism for splitting the N and Δ, Σ and Λ, and so on - a job usually reserved for the one gluon exchange interaction[6),7)]. Both because of its size and its spin dependence one expects substantial changes in the paramaters of the MIT bag model, and hence in the predictions for the more exotic, multiquark bags.

In order to determine the new bag model parameters we shall use the spherical, static cavity approximation[7)]. The pionic corrections will be treated as a perturbation to the masses found by applying the non-linear boundary condition ($\partial M/\partial R = 0$) to the rest of the bag energy. In this way we avoid the collapse of the bag[8)], caused by the $R^{-3.5}$ behaviour[9)] of the attractive pionic self-energy term. Such a term would be dominant at small R, driving the over-all bag mass to zero. Since the chiral bag models neglect the finite size of the pion itself, the calculations for small R cannot be trusted[10)]. Moreover, it seems unlikely on the basis of QCD that the pion should play a major role in determining hadronic sizes. Clearly in our work the bag size is still determined by B, the energy density required to make a bubble in the QCD vacuum[5),7)].

There is one other uncertainty in determining the bag parameters - that is deciding which masses to use for the unstable hadrons. Previous bag model calculations have usually used the resonance energy (in, say, a Breit-Wigner fit) for unstable hadrons. For example, the Δ is usually taken to have a mass of about 1.23 GeV. Of course, if one has a complete dynamical model for the background in a resonant system, the underlying resonance position can be determined unambiguously. This idea was illustrated by the Cloudy Bag Model (CBM) description of the Δ resonance[2),5)], although even there only the most important (Chew-Low) background terms were included. In general one would not expect to have such a clear idea of the most important background. Moreover, it would be impractical in a global fit of the kind which we are undertaking to first make a coupled channel calculation for each unstable resonance.

A much simpler approach was proposed by Jaffe and Low[11]. They suggested identifying bag model masses as 'primitives', or poles in the P matrix - rather than the S matrix. In the case of the Δ there is a large shift from the resonance position to the P-matrix pole[12]. For instance, with a matching radius of the order 1.3fm, the P matrix pole of the Δ occurs at 1.31 GeV. The value of 1.31 Gev, however, takes into account only the open $N\pi$ channel. If one were to include closed channels, like $\Delta\pi$, the shift would be even greater. Thus, the analysis using the P-matrix formalism is also model dependent. Furthermore, the primitive masses for stable particles like the nucleon are also shifted because of closed channels.

In view of these ambiguities we have decided to follow the usual practice of using observed resonance positions in the determination of bag model parameters. To some extent this pragmatic approach is supported by the CBM analysis of the Δ. There one could unambiguously define the mass of the Δ bag, including pionic self-energy corrections, and it turned out to be very close to the observed resonance energy. This certainly does not establish the result in the general case, but it is indicative.

For the exotic, six quark bags we do not know in general how to calculate their experimental consequences. Instead we shall compare our results with the predictions of the original MIT model[13),14]. Of special interest is the lowest double strange $(Y = 0)$ dibaryon (H dibaryon), which according to Jaffe's initial work should be bound by 80 MeV[13]. Once pionic corrections are included this state moves much closer to threshold, and it is either unbound or very weakly bound. It may therefore be much harder to identify, which may explain why our experimental colleagues have not been successful in finding it[15),16].

2. - BAG ENERGY INCLUDING PIONS - ORDINARY BARYONS AND MESONS

In the limit of a static, spherical cavity[7),5] the usual expression for the energy of the MIT bag is

$$E(R) = E_V + E_Q + E_M \quad . \tag{2.1}$$

Here E_V is the energy required to make a hole in the vacuum (BV), minus a phenomenological term $(-Z_o/R)$, originally attributed to zero point energy[7]. More recently the latter has been associated with centre of mass[17),18),19),5)] and colour electric[20)-22)] contributions. We shall comment on the latter in the final section. However, all calculations have been performed in the same way as the original MIT bag model, using

$$E_V = \frac{4\pi}{3} B R^3 - \frac{Z_o}{R} , \tag{2.2}$$

with Z_o constant.

The quark kinetic energy is

$$E_Q = \sum_i \frac{\varepsilon(m_i R)}{R} , \tag{2.3}$$

where ε is the usual eigenfrequency of the lowest mode in the cavity resulting from the linear boundary condition, which is a function of the product of quark mass and bag radius, $\mu = m_i R$ We have

$$\varepsilon^2 = \mu^2 + x^2, \tag{2.4}$$

where x is a function of μ, satisfying

$$\tan(x) = x / (1 - \mu - \varepsilon) . \tag{2.5}$$

For massless quarks $\varepsilon = x = 2.043$.

The last term in Eq. (2.1) is the colour magnetic interaction associated with the exchange of a single gluon between two quarks inside the bag. It is given by the expression

$$E_M = - \sum_{i>j} \alpha_s \frac{M(m_i R, m_j R)}{R} (F^c \underline{\sigma})_i \cdot (F^c \underline{\sigma})_j , \tag{2.6}$$

where α_s is the effective quark-gluon coupling constant, and F^c and $\underline{\sigma}$ are respectively the colour and spin of the quark. The function $M(\mu_i, \mu_j)$ is a wave function overlap. Its precise form was given in Ref.7); for $\mu \leq 1.5$ it can be well approximated as:

$$M(0,\mu) \simeq 0.177 - 0.025\mu ,$$
$$M(\mu,\mu) \simeq 0.177 - 0.043\mu . \tag{2.7}$$

As explained in the introduction we obtain the masses of baryons and mesons from

$$M = \min_R \{ E(R) \} + E_p , \qquad (2.8)$$

where E_p is the pion self energy. We have chosen to use the simple phenomenological form[1)]

$$E_p = - \frac{1}{p R^3_{min}} \sum_{i,j} (\underset{\sim}{\sigma} \underset{\sim}{\tau})_i \cdot (\underset{\sim}{\sigma} \underset{\sim}{\tau})_j , \qquad (2.9)$$

where p is an adjustable constant. This corresponds to keeping only intermediate states with quarks in the lowest radial state, and treating all such states as degenerate. The eigenvalues of the operator

$$\Sigma_{op} = - \sum_{(i,j) \varepsilon (u,d)} (\underset{\sim}{\sigma} \underset{\sim}{\tau})_i \cdot (\underset{\sim}{\sigma} \underset{\sim}{\tau})_j , \qquad (2.10)$$

were given in Refs 3) and 4) for the ordinary baryons and mesons - see also the Appendix of this paper.

Using Eq. (2.8) we choose to fit the masses of the $\omega(782)$, $N(939)$, $\Delta(1232)$, and $\Omega(1672)$, as well as the mass splitting of the Λ and Σ (77 MeV) in order to fix the five parameters of the model $(B, Z_o, \alpha_s, M_s, p)$ - as usual $m_u = m_d = 0$. These parameters are given in Table 1, together with the predictions for all the low-lying mesons and baryons. For the mesons the results are not very satisfactory, suggesting (not surprisingly) that we need a more sophisticated treatment of the pionic corrections to the mesons. (The pion itself should really be excluded, and the η, η' problem is not unique to the bag model. However we show these for completeness.)

On the other hand, the resulting fit to the baryon spectrum is quite good. The size of the pionic correction E_p, and the bag radii are in qualitative agreement with Refs. 3) and 4). There are a number of interesting features of the parameters that come out. First, as discussed by a number of people[2)-4),23)]. The colour coupling constant is significantly reduced; we find a reduction of about 35%. In addition the strange quark mass is reduced to 218 MeV (from 280 MeV) - see also Ref 9) - which is closer to the 150 MeV preferred by current algebra. Finally we note that the agreement between the phenomenological value of $p^{1/2}$, namely 1.49 GeV, and that computed on the basis of chiral symmetry[1,5)],

$$P^{1/2} = \left(\frac{400\pi}{3}\right)^{1/2} \frac{f_\pi}{g_A} = 1.52\,\text{GeV}, \tag{2.11}$$

is excellent.

We cannot resist the tempatation to mention a fit to the P-matrix positions of baryons and mesons, although there are many questions involved about the procedure - as discussed in the introduction. Taking the simplest and least model dependent approach we determine the P-matrix poles from scattering in open channels. Of the five particles we used to fit the baryon and meson spectrum only the (unstable) Δ has a P-matrix pole with a position different from the S-matrix pole. We thus fit to the $\omega(782)$, $N(939)$, $\Delta(1310)$, $\Omega(1672)$, and the $\Lambda - \Sigma$ mass difference (77 MeV). It is surprising - and maybe accidental - that an excellent fit is obtained with parameters $B^{1/4} = 0.169$ GeV $Z_o = 1.80$, $\alpha_s = 1.69$, $M_s = 0.181$ GeV, and $P^{1/2} = 1.85$. The kaon in this fit for example has a mass of 498 MeV, the Λ has a mass of 1109 MeV.

3. - BAG MODEL PREDICTIONS FOR THE DIBARYONS

In order to calculate the masses of the baryon number 2 bag states we follow the work of Ref. 24). The colour magnetic interaction is approximated by

$$E_M = m\,\Delta_{op}\,, \tag{3.1}$$

where $m(R)$ is the strength averaged over non-strange and strange quarks, and Δ_{op} is the operator

$$\Delta_{op} = -\sum_{i>j} (F^c \underline{\sigma})_i \cdot (F^c \underline{\sigma})_j\,, \tag{3.2}$$

which for N quarks has the expectation value

$$\Delta = N(10-N)/4 + S(S+1)/3 + f_F^2 + f_C^2/2. \tag{3.3}$$

Here S is the total spin and f_F^2 and f_C^2 are the eigenvalues of the SU(3) quadratic Casimir operators for flavour and colour.

Once again the pionic corrections are calculated after minimizing the rest of the bag energy. They are given by

$$\Sigma_p = \frac{\Sigma_{op}}{p\ R^3_{min}} , \tag{3.4}$$

where Σ_{op} was defined in Eq.(2.10). For N non-strange quarks the expectation value of Σ_{op} is given by [see Eq. (A.6)].

$$\Sigma = +\frac{7}{3} N^2 - 28 N + 8 f_c^2 + 4 S(S+1) + 4 I(I+1), \tag{3.5}$$

where S and I are the total spin and isospin of the non-strange quarks, and f_C^2 is the eigenvalue of the SU(3) quadratic Casimir operator for colour-again for the non-strange quarks only. As discussed in the Appendix Eq.(3.5) agrees with the result of Jaffe[1] for $N = 3$, but is different for larger N.

The results for the non-strange $(Y = 2)$ dibaryons are given in Table 2. In this case the inclusion of pionic corrections (column B) does not greatly alter the original predictions based on the MIT model[13),14)] (column A). There is some tendency for the smaller colour coupling constant in case B to yield lower masses for dibaryons with large, positive Δ.

For the strange dibaryons the inclusion of pionic corrections is more complicated, because we need to know the spin and colour of the non-strange quarks alone. One finds that the colour magnetic contribution E_M [Eq. (2.6)] and the pionic correction [Eq. (2.9)] do not commute. Instead of doing the full calculation of the mixing between all dibaryons with a given spin and isospin - total spin and isospin still do commute with E_M and E_p -, we only indicate the minumum and maximum value of the correction. For the low-lying states of greatest interest these upper and lower estimates are very close. We show the calculated masses of the lowest $Y = 1$ and $Y = 0$ dibaryons in Tables 3 and 4 respectively. By far the most dramatic change is the increase in mass of the lowest $Y = 0$ dibaryon (H). While this is still the most interesting state to look for, it appears quite likely that it may not be bound.

There are two main reasons that we find to make the H dibaryon less bound once pion corrections are included - although actually all contributions to the energy do change. First, as mentioned earlier the colour coupling constant α_s is significantly reduced; this reduces the colour magnetic attraction for the H dibaryon. Second, a free Λ receives some -130 MeV self-energy because of its pion cloud. The H dibaryon has a radius about 20% larger than the Λ.

Because of the strong dependence of the pion self-energy on the bag radius, $\sim R^{-3}$, we expect the correction to be about half the correction for two Λ's (we actually find -110 MeV). The result is that the H has a higher mass than in the original MIT calculation where this pion correction was not included.

4. - DISCUSSION

The main results of this work are summarized in Tables 2 - 4. By far the most significant result is the increase in mass of the lowest $Y=0$ dibaryon, discussed in detail in section 3. In this final section we will not repeat what has already been said. Instead, we shall make some brief comments on the possible relevance of our results to experiment, including the implications of recent work on the quark self-energy[20)-22)].

There is little chance that there will be any dramatic experimental consequences of the non-strange states listed in Table 2. They all lie far above the appropriate threshold - be it NN, NΔ (and NNπ) or $\Delta\Delta$ (and NN$\pi\pi$) and will be very broad. This has been demonstrated explicitly within the framework of the P-matrix formalism[25)]. On the other hand, if the masses would be lower - that is, near or below the thresholds - dibaryons might produce striking consequences in NN or πd scattering. In this case the small width of, for example, the $I=2$, $S=1$ state might compensate enough for its small (isospin violating) coupling to those channels to produce a clear signal over a narrow energy region. One is tempted to suggest such a possibility to explain the discrepancy between the recent SIN and LAMPF measurements of t_{20} in πd scattering[26),27)] - although it is probably an experimental problem.

We would hesitate to even mention this unlikely possibility were it not for the recent appearance of a mechanism which might conceivably produce a downward shift in mass for exotic states - with respect to our calculation.

It has been argued by Chin et al.[20)], and by Breit[21)], on the basis of the soliton bag model[28),29)], that the $-Z_0/R$ term [Eq. (2.2)] in the usual MIT model results from the quark self-energy. The constant Z_0 is then given by

$$Z_0 = N \lambda \alpha_s , \tag{4.1}$$

where N is the number of confined quarks, and λ is some - still controversial[20)-22)] - number. In Briet's work $\lambda = 0.25$, which for baryons and with the MIT value of $\alpha_s = 2.2$ is in excellent agreement with $Z_o = 1.8$. Clearly if all of the phenomenological $-Z_o/R$ term were interpreted this way, we would get twice as big a contribution for dibaryon states (with $N = 6$ instead of 3), a reduction in energy of typically 100 - 200 MeV.

On a more realistic level it seems to us that a fairly convincing case can be made that centre of mass corrections contribute of the order 0.6 -0.8 to Z_o for the usual baryons[4),17)-19)]. With our coupling constant, $\alpha_s = 1.4$, and $Z_o = 1.31$ a value $\lambda \approx 0.15$ is required. If this combination of effects is indeed the origin of the infamous Z_o term, there will be no major change in the energies of the exotic bag states form those given in Tables 2 - 4. A more precise statement than this will have to wait until we understand all of the difficulties - centre of mass corrections, quark and gluon self energies and the appropriate mass parameter for comparison with experiment - much better than we do presently.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge a number of informative discussions with P. Guichon, L. Heller, and R. Jaffe. In addition we would like to thank T.D. Lee for drawing the work of Ref.21) to our attention. Finally we would like to acknowledge the assistance of P. Guichon in first proving the result of the Appendix for the specific case $N = 6$.

The work of P.M.J. was supported by the U.S. Department of Energy.

APPENDIX

In order to find the expectation value of the spin-isospin operator Σ_{op}, appearing in Eq.(2.10) we use the anti symmetry of the full N-quark wave function. That is, we use the fact that (for $i \neq j$)

$$P_{ij}^{C}\, P_{ij}^{I}\, P_{ij}^{S} = -1, \tag{A.1}$$

and hence

$$P_{ij}^{C} = -P_{ij}^{I}\, P_{ij}^{S}, \tag{A.2}$$

where the P_{ij} are permutation operators for colour, isospin, and spin[24],

$$\begin{aligned} P_{ij}^{C} &= 1/3 + 2\, F_i^{C} \cdot F_j^{C}, \\ P_{ij}^{I} &= 1/2\,(1 + \underset{\sim}{\tau}_i \cdot \underset{\sim}{\tau}_j), \\ P_{ij}^{S} &= 1/2\,(1 + \underset{\sim}{\sigma}_i \cdot \underset{\sim}{\sigma}_j). \end{aligned} \tag{A.3}$$

Substituting (A.3) into (A.2) we find (for $i \neq j$)

$$(\underset{\sim}{\sigma}\underset{\sim}{\tau})_i \cdot (\underset{\sim}{\sigma}\underset{\sim}{\tau})_j = -7/3 - 8\, F_i^{C}\, F_j^{C} - \underset{\sim}{\sigma}_i \cdot \underset{\sim}{\sigma}_j - \underset{\sim}{\tau}_i \cdot \underset{\sim}{\tau}_j. \tag{A.4}$$

Finally, using

$$(\underset{\sim}{\sigma}\underset{\sim}{\tau})_i \cdot (\underset{\sim}{\sigma}\underset{\sim}{\tau})_i = 9, \tag{A.5}$$

we obtain the desired result

$$\begin{aligned} &\langle -\sum_{i,j} (\underset{\sim}{\sigma}\underset{\sim}{\tau})_i \cdot (\underset{\sim}{\sigma}\underset{\sim}{\tau})_j \rangle \\ &= \frac{7}{3} N^2 - 28N + 8 f_c^2 + 4 S(S+1) + 4 I(I+1), \end{aligned} \tag{A.6}$$

where f_C^2 is the eigenvalue of the colour, quadratic Casimir operator.

REFERENCES

1) R.L. Jaffe, "The bag", Lectures at the 1979 Erice School "Ettore Majorana".

2) S. Théberge, A.W. Thomas and G.A. Miller, Phy. Rev. (1980) 2838; D23 (1981) 2106(E);
A.W. Thomas, S. Théberge and G.A. Miller, Phys. Rev. D24 (1981) 216.

3) W.N. Cottingham, K. Tsu and J.M. Richard, Nocl. Phys. B179 (1981) 541

4) F. Myhrer, G.E. Brown and Z. Xu, Nucl. Phys. A362 (1981) 317.

5) A.W. Thomas, "Chiral Symmetry and the Bag Model", CERN preprint TH-3368, Triumf preprint TRI-PP-82-29 (1982), to be published in Adv. Nucl. Phys. 13.

6) A. De Rujula, H. Georgi and S. Glashow, Phys. Rev. D12 (1975) 147

7) T. DeGrand, R.L. Jaffe, K. Johnson and J. Kiskis, Phys. Rev. D12 (1975) 2060

8) V. Vento et al., Nucl. Phys. A345 (1980) 413.

9) S. Théberge, Ph.D. Thesis, University of British Columbia (March 1982);
S. Théberge and A.W. Thomas, Phys. Rev D25 (1982) 284 and CERN preprint TH-3290 (1982).

10) J. De Kam and H. Pirner, Heidelberg University preprint (1982)

11) R.L. Jaffe and F.E. Low, Phys. Rev. D19 (1979) 2105.

12) E.J. Moniz, private communication. See also L. Heller, J.C. Martinez and E.J. Moniz, to be published.

13) R.L. Jaffe, Phys Rev. Lett. 38 (1977) 195.

14) A.T. Aerts, P.J. Mulders and J.J. de Swart, Phys. Rev. D17 (1978) 260.

15) E. Pauli, in Proceeding of 2nd Kaon Workshop, Triumf report TRI-81-14 (1982).

16) See also A.T. Aerts and C. Dover, Brookhaven National Laboratory preprint (1982).

17) F. Donghue and K. Johnson, Phys. Rev. D21 (1980) 1975.

18) C.W. Wong, Phys. Rev. D24 (1981) 1416

19) C.E. Carlson and M. Chachkhunashvili, Nordita preprint (August, 1981).

20) S.A. Chin, A.K. Kerman and X.H. Yang, MIT preprint CTP-919 (1982).

21) J.D. Breit, Columbia University preprints CU-TP-229 and CU-TP-223 (1982).

22) T.H. Hansson and R.L. Jaffe, MIT preprint CTP-1026 (1982).

23) S. Théberge, G.A. Miller and A.W. Thomas, Can. J. Phys. 60 (1982) 59

24) P.J. Mulders, A.T. Aerts and J.J. de Swart, Phys. Rev. D19 (1979) 2635

25) Se for example P.J. Mulders, Los Alamos National Laboratory preprint LA-UR-82-1766 (1982), to be published.

26) W. Grüebler et al., Phys. Rev. Lett. 49 (1982) 444.

27) J. Holt et al., Phys Rev. Lett. 47 (1981) 472.

28) R. Friedberg and T.D. Lee, Phys. Rev. D18 (1978) 2623.

29) R. Goldflam and L. Wilets, Phys. Rev. D25 (1982) 1951.

Table 1: Result for bag parameters and masses of baryons and mesons including pionic corrections [Eqs. (2.9) and (2.10)]. R_{min} is given in GeV^{-1}, other quantities in GeV.

$B^{1/4} = 0.151$ GeV, $Z_o = 1.31$, $\alpha_s = 1.41$, $m_s = 0.218$ GeV, $p^{1/2} = 1.49$ GeV

Particle	R_{min}	E_V	E_Q	E_M	E_p	M	M_{exp}
N	5.058	0.025	1.212	-0.099	-0.199	0.939	0.939
Λ	5.034	0.020	1.339	-0.099	-0.127	1.132	1.116
Σ	5.034	0.020	1.339	-0.079	-0.071	1.209	1.193
Ξ	5.009	0.014	1.467	-0.088	-0.032	1.361	1.318
Δ	5.328	0.086	1.150	0.094	-0.098	1.232	1.232
Σ^*	5.306	0.081	1.278	0.085	-0.060	1.383	1.385
Ξ^*	5.283	0.076	1.405	0.076	-0.028	1.529	1.533
Ω	5.261	0.071	1.533	0.069	0.0	1.672	1.672
π	4.049	-0.178	1.009	-0.247	-0.163	0.420	0.138
η_n +)	4.049	-0.178	1.009	-0.247	0.0	0.583	0.549(η)
η_s +)	3.987	-0.190	1.262	-0.198	0.0	0.873	0.958(η')
K	4.018	-0.184	1.135	-0.218	-0.063	0.670	0.496
ρ	4.659	-0.060	0.877	0.072	-0.071	0.818	0.776
ω	4.659	-0.060	0.877	0.072	-0.107	0.782	0.782
φ	4.606	-0.070	1.128	0.055	0.0	1.113	1.020
K^*	4.632	-0.065	1.003	0.062	-0.041	0.959	0.892

+) The n and s denote the pure non-strange and pure strange η meson, respectively.

Table 2: Masses of the non-strange (Y = 2) dibaryons in the original MIT bag model calculation[13),14)] (A), and in the present calculation including pionic corrections (B)

				A		B	
I	S	Δ	Σ	R(GeV^{-1})	M(GeV)	R(GeV^{-1})	M(GeV)
0	1	2/3	-76	6.60	2.16	6.41	2.18
1	0	2	-76	6.68	2.23	6.45	2.24
1	2	4	-52	6.79	2.35	6.52	2.36
0	3	4	-36	6.79	2.35	6.52	2.38
2	1	20/3	-52	6.93	2.50	6.61	2.46
3	0	12	-36	7.19	2.79	6.78	2.69

Table 3: Masses of lowest two Y = 1 dibaryons in cases A and B (see caption of Table 2).

				A		B	
I	S	Δ	Σ	R(GeV^{-1})	M(GeV)	R(GeV^{-1})	M(GeV)
1/2	1	-7/3	-67/-57	6.38	2.16	6.28	2.20/2.22
1/2	2	-1	-57/-39	6.47	2.23	6.33	2.27/2.31

Table 4: Masses of lowest Y = 0 dibaryon (H) in cases A and B (see caption of Table 2).

				A		B	
I	S	Δ	Σ	R(GeV^{-1})	M(GeV)	R(GeV^{-1})	M(GeV)
0	0	-6	-56/-48	6.09	2.15	6.11	2.22/2.23