Energy Dependence of the Delta Resonance: Chiral Dynamics in Action

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Abstract. There is an important connection between the low energy theorems of QCD and the energy dependence of the Δ resonance in π-N scattering, as well as the closely related γ∗N → Nπ reaction. The resonance shape is due not only to the strong π-N interaction in the p wave but the small interaction in the s wave; the latter is due to spontaneous chiral symmetry breaking in QCD (i.e. the Nambu-Goldstone nature of the pion). A brief overview of experimental tests of chiral perturbation theory and chiral based models is presented.

1 Introduction

Since the discovery of the Δ resonance (the first excited state of the nucleon) by Fermi’s group it has been well known that it dominates low energy πN scattering and the closely related γ∗N → Nπ reaction. In the intervening years there has been a great deal of experimental and theoretical activity in this classical field of πN physics. This is central to our understanding of nuclei (the nucleon-nucleon potential) and of the long range properties of hadrons through their virtual emission and absorption of pions. In this article we shall stress the less well known relationship between the spontaneous hiding of chiral symmetry in QCD, its subsequent low energy theorems, and the energy dependence of the Δ resonance. A brief overview of low energy πN physics is presented with an emphasis on electromagnetic pion production. It is shown that theoretical calculations based on spontaneous chiral symmetry hiding economically summarize the wealth of accurate data that have been taken in the past two decades. We present this as a tribute to S. N. Yang who has been a leader in using a chiral

¹The modern values for the Δ are I(JP) = 3/2(3/2⁺), center of mass energy \( W = 1232 \text{ MeV} \), width \( Γ = 118 \text{ MeV} \).
based pion cloud model (the Dubna-Mainz-Taipei or DMT model\[6\]) to successfully predict the observables in these low energy reactions.

The QCD Lagrangian can be written as a sum of two terms, \( L_0 \) which is independent of the lightest quark masses (up, down) and \( L_m \) which contains the masses of the two light quarks\[7\]. Consider the chiral limit in which the light quark masses \( m_q \to 0 \). As is well known, the vector current is conserved while the axial vector current is conserved only in the chiral limit (i.e. \( m_q \to 0 \)) and slightly non-conserved in the real world. This is one of the approximate symmetries of QCD on which chiral perturbation theory (ChPT) is based\[3, 4, 7\]. Despite the fact that the light quark mass independent part of the QCD Lagrangian, \( L_0 \), has chiral symmetry, matter does not seem to obey the rules. The chiral symmetry is expected to show up by the parity doubling of all hadronic states: i.e., the proton with \( j^P = 1/2^+ \) would have a 1/2\(^-\) partner (the Wigner-Weyl manifestation of the symmetry). Clearly, this is not the case. This indicates that the symmetry is spontaneously hidden (often stated as spontaneously broken) and is manifested in the Nambu-Goldstone mode; the parity doubling occurs through the appearance of a massless pseudo scalar \((0^-)\) meson. The opposite parity partner of the proton is a proton and a “massless pion” (Goldstone Boson). The consequence of this for the \( \pi N \) interaction in momentum space is:

\[
V_{\pi N} = g_{\pi N} \sigma \cdot p_\pi
\]

where \( \sigma \) is the nucleon spin and \( p_\pi \) is the pion momentum. In accordance with Goldstone’s theorem, this interaction \( \to 0 \) as the pion momentum \( \to 0 \). Furthermore, the coupling constant \( g_{\pi N} \) can be computed from the Goldberger-Treiman relation\[7\] and chiral corrections\[8\] and is accurate to the few % level. The \( \pi N \) interaction is very weak in the s wave and strong in the p wave which leads to the \( \Delta \) resonance, the tensor force between nucleons, and to long range non-spherical virtual pionic contributions to hadronic structure. These salient features of the \( \pi N \) interaction have been known for decades and can be found in most textbooks on nuclear physics. However, they are usually based on empirical findings such as the pseudoscalar nature of the pion and on the empirically determined coupling constant \( g_{\pi N} \). What is different in this presentation is the fact that it is based on QCD and that these empirical findings are in fact predicted by the considerations of spontaneous chiral symmetry hiding in QCD.

Equation (1) shows that the cross sections for \( \pi N \) scattering must go to zero at low energies in the chiral limit. This was first derived before the advent of QCD using current algebra (now recognized as the lowest order chiral perturbation theory (ChPT) calculation \( O(p^2) \)) for \( a(\pi, h) \), the s wave \( \pi \) hadron scattering length\[9\]. The result is

\[
a_I(\pi, h) = -I_\pi \cdot I_h m_\pi / (4 \pi F_\pi) \quad \text{where} \quad I = I_\pi + I_h \quad \text{is the total isospin,} \quad I_\pi \quad \text{and} \quad I_h \quad \text{are the isospin of the pion and hadron respectively,} \quad F_\pi \quad \text{is the pion decay constant, and} \quad \Lambda_x = 4 \pi F_\pi \simeq 1 \text{ GeV} \quad \text{is the chiral symmetry breaking scale}\[9\]. \text{Note that} \quad a(\pi, h) \to 0 \quad \text{in the chiral limit,} \quad m_\pi \to 0, \quad \text{as it must to obey Goldstone’s theorem. Also note that} \quad a(\pi, h) \simeq 1/\Lambda_x \simeq 0.1 \text{ fm} \quad \text{which is small compared to a typical strong interaction scattering length of} \sim 1 \text{ fm. This small scattering length is obtained from the explicit chiral symmetry breaking due to the finite quark masses. The predictions of ChPT for} \pi N \text{ scattering lengths have}
\]
been verified in detail in a beautiful series of experiments on pionic hydrogen and deuterium at PSI\cite{10}.

Low energy electromagnetic production of Goldstone Bosons is as fundamental as Goldstone Boson scattering for two reasons: 1) the production amplitudes vanish in the chiral limit (as in scattering); and 2) the phase of the production amplitude is linked to scattering in the final state by unitarity or the final state interaction (Fermi-Watson) theorem suitably modified to take the up, down quark masses into account\cite{11}. First consider the low energy limit of the electric dipole \(E_{0^+}\) for s wave photo-pion production\cite{12}:

\[
E_{0^+}(\gamma p \rightarrow \pi^0 p) = -D_0 \mu (1 + O(\mu) + ...) \rightarrow 0
\]

\[
E_{0^+}(\gamma p \rightarrow \pi^+ n) = \sqrt{2} D_0 / (1 + \mu + ...)^{3/2} \rightarrow \sqrt{2} D_0
\]

\[
\mu = m_\pi / M \rightarrow 0
\]

\[
D_0 = e \cdot g_{\pi N} / 8\pi M = 24 \cdot 10^{-3} (1 / m_\pi)
\]

where \(M\) is the nucleon mass and the right arrow denotes the chiral limit \((m_u, m_d, m_\pi \rightarrow 0)\). Equation (2) shows that for neutral pion production the amplitude vanishes in the chiral limit. For charged pion production, there is a different low energy theorem\cite{12}. Therefore, the amplitude that is most sensitive to explicit chiral symmetry breaking is neutral pion production and most of the modern experiments have concentrated on this channel. In general, ChPT to one loop calculated in the heavy Fermion approximation has been highly successful in calculating the observed cross sections and linearly polarized photon asymmetry\cite{12}.

\[
\pi N \text{ and } \gamma N \rightarrow \pi N \text{ Experiments}
\]

2.1 Energy Dependence of the \(\Delta\) Resonance

The application of the ideas of the previous section to data from low energy \(\pi N\) scattering and electromagnetic pion production from the nucleon is instructive. In this section we shall take a broad view of the energy dependence of the \(\pi N\) interaction from threshold through the \(\Delta\) resonance as revealed by total cross section data (amplifying a brief previous presentation\cite{5}). Figure 1 shows the total cross sections for \(\pi^+ p\) scattering\cite{13}. These reactions have a strong \(\Delta\) resonance. As expected, the \(\pi^+ p\) cross section goes to zero near threshold. The small, but not zero, cross section for \(\pi^0 p\) scattering near threshold is due to Coulomb effects. These two cross sections clearly show the \(\Delta\) resonance without any interference (the small shift between them is due to the mass difference of the \(\Delta^0\) and \(\Delta^+\)). Indeed these cross sections are a textbook example of an isolated resonance. Although not usually mentioned in textbooks it is the combination of a strong resonance and a small cross section at threshold that produces this beautiful example (as predicted by chiral dynamics)! This can be verified experimentally in the case of photo-pion production shown in Fig. 2. If we consider the \(\gamma p \rightarrow \pi^0 p\) reaction, the cross section near threshold goes to zero as indicated by Eq. (2) and the \(\Delta\) resonance looks very similar to \(\pi N\) scattering. On the other hand, for the \(\gamma p \rightarrow \pi^+ n\) reaction there is strong s wave production starting at threshold, due to the Kroll-Ruderman low energy theorem (see Eq. (2)). In this
case the $\Delta$ resonance curve is superimposed on the strong s wave amplitude and looks quite different!

From Figure 2 we see that the two model curves are in good agreement with the data. These are the phenomenological MAID \cite{14} and the pion cloud DMT (Dubna-Mainz-Taipei) \cite{6} models, in which S. N. Yang plays a major role. The reason for this good agreement with experiment is that both models have the low energy theorems of QCD as well as an accurate description of the $\Delta$ resonance.

The energy dependence of the $\Delta$ resonance can also be seen very clearly in the $\delta_{33} (I = J = 3/2)$ phase shift in $\pi N$ scattering and in the $M_{1+}(I = 3/2)$ for the $\gamma^* N \to \pi N$ reaction (for the notation see \cite{15,16}). These have the advantage that they show the resonance directly. Since the observables are bilinear combinations of the transition matrix elements neither the phase shifts nor multipoles are directly observable. In general they have been extracted from experiment by
Figure 3. Left panel: The $\delta_{33}$ phase shift for $\pi N$ scattering versus $W$, the center of mass energy, from threshold through the $\Delta$ resonance. The points are the SAID single energy fits to the data and the curve is the smooth energy dependent fit[13]. Right panel: The absolute value of the resonant $M_{1+}(I = 3/2)$ multipole for the $\gamma p \rightarrow \pi N$ reaction as a function of $W$. The points are from the SAID single energy analysis[13] and the curves are the results of the DMT[6] and MAID[14] models.

model dependent methods. In this case, where we are exhibiting the dominant amplitudes, the model errors are believed to be small. In Figure 3 we present these quantities from the SAID analysis[13]. It can be seen that $\delta_{33}$ for $\pi N$ scattering passes through 90° in the upwards direction at $W = 1232$ MeV which defines the $\Delta$ resonance position. The width comes from a Breit-Wigner fit to the energy dependence. The magnitude of the resonant $M_{1+}(I = 3/2)$ amplitude for the $\gamma N \rightarrow \pi N$ reaction is also shown in Fig. 3. It also defines the same position and width for the $\Delta$ as does $\pi N$ scattering. It can also be seen that the MAID[14] and SAID[13] models are in good agreement with this dominant photo-pion resonant amplitude.

2.2 Tests of Theoretical Calculations

In this section we give a brief overview of the present status of experimental tests of chiral perturbation theory (ChPT) and pion cloud model calculations of the electromagnetic pion production for the threshold and $\Delta$ regions.

A great deal of effort has gone into the study of the near threshold $\gamma p \rightarrow \pi^0 p$ reaction experimentally at Mainz[17] and Saskatoon[18] and with ChPT calculations[12]. The unpolarized cross sections were accurately measured and, despite their small size, the results from Mainz and Saskatoon are in reasonable agreement. The experiments were performed using tagged photons for energies between threshold (144.7 MeV) and 166 MeV. For the Mainz data there were sufficient statistics to bin the cross section data in $\simeq 1$ MeV steps. The ChPT calculations[12] have proven to be quite accurate in fitting the cross sections with only five empirical low energy constants at $O(p^4)$. In addition, the polarized

\footnote{Due to correlations in the fitting there are effectively only three independent low energy parameters.}
linear photon asymmetry $\Sigma$ was also measured at Mainz. Here the statistics only allowed us to group the data from threshold to 166 MeV in one cross section averaged energy bin of 159.5 MeV \[17\]. The results are shown in Fig. [4]. Here the improvement in the $O(p^4)$ ChPT calculation over the $O(p^3)$ version is seen. This is obtained by fitting the data using the additional low energy constants that appear at $O(p^4)$. This is an indication of how sensitive this observable is to the small $p$ wave multipoles. Another indication of this is that the dispersion theory calculation, which does agree with the unpolarized cross section data, does not agree with $\Sigma$. This is probably due to a small discrepancy in the $M_{1-}$ multipole which is not well constrained by the other data on which this calculation is based. More recent data taken at Mainz are anticipated to produce five values of $\Sigma$ between threshold and 168 MeV \[19\].

Most of the dynamical models do not accurately predict cross sections for the near threshold $\gamma p \rightarrow \pi^0 p$ reaction. The exception to this is the DMT model which has accurately predicted the observed cross sections \[20\] [6]. However, it does not accurately predict the polarized photon asymmetry $\Sigma$. Again, as a sign of the extreme sensitivity of this observable, when they arbitrarily reduce their $M_{1-}$ amplitude by 15% they have agreement with the observed value of $\Sigma$ shown in Fig. [4]. However the prediction of this amplitude is not as robust due to the tail of the Roper resonance, vector meson effects, and final state interactions \[20\] [6].

Having discussed the comparison between the calculations and experiment it is of interest to look at the major ingredients of the ChPT \[12\] and DMT \[6, 20\] calculations. ChPT employs chiral symmetric Lagrangians with explicit chiral symmetry broken by the quark mass terms. It is an order by order expansion in which unitarity is restored as the order increases. For example, at the tree level unitarity is completely absent, but is mostly restored by the one loop calculations \[12\]. It is gauge invariant and preserves crossing symmetry. By contrast the DMT model has chiral symmetry in the Lagrangian and is unitary to all orders: it uses a pion cloud model for the $\pi N$ matrix which gives good agreement with the $\pi N$ phase shifts \[21\]. It enforces gauge invariance but violates crossing symmetry.

A sensitive way to compare theory and experiment is at the level of the multipoles. Since the observables are bilinear combinations of the multipoles \[16\] this process is often model dependent. However, in the case of near threshold photopion production an approximate, but reasonably accurate, model independent multipole extraction is possible. This is because there are only five real numbers to extract from the experiments (see e.g. \[22\] for a more detailed discussion). These are the $s$ wave electric dipole amplitude $E_{0+}$ which is complex, and three $p$ wave amplitudes which are approximately real numbers in this energy region. Due to the low energy theorems of QCD \[12\] (see Eq. [2]) the $p$ wave amplitudes tend to dominate even relatively close to threshold. The real part of the $s$ wave electric dipole amplitude $\text{Re} E_{0+}$ is extracted from the data using the interference between $s$ and $p$ waves which goes as $\cos(\theta_\pi)$ in the differential cross section and leads to significant errors. The results for $\text{Re} E_{0+}$ versus photon energy are plotted in Fig. [4]. There is reasonable agreement between the Mainz and Saskatoon points as well as with ChPT \[12\] and the unitary model calculations \[22\]. The sharp downturn in $\text{Re} E_{0+}$ between the threshold at 144.7 MeV and the $\pi^- n$
threshold at 151.4 MeV is due to a unitary cusp caused by the interference between the $\gamma p \rightarrow \pi^0 p$ and $\gamma p \rightarrow \pi^+ n$ channels\cite{11}. The magnitude of the cusp is $\beta = \text{Re}(E_0^+) \cdot a_{\text{cex}}(\pi^+ n \rightarrow \pi^0 p)$ which is measured to an accuracy of $\approx 30\%$ from the data shown\cite{22}. The reason for this accuracy limitation is due to the fact that in addition to the experimental errors in $\text{Re}(E_0^+)$, this quantity is a sum of a (not precisely known) smooth function and a more rapidly varying cusp\cite{11, 22}. Therefore it is important to measure $\text{Im}(E_0^+)$ which starts from close to zero at the $\pi^+ n$ threshold energy and rises rapidly as $\beta p_{\pi^+}$. This makes the extraction of $\beta$ as accurate as the measured asymmetry for $\pi^0$ photoproduction from a polarized target normal to the reaction plane. We are planning to conduct future experiments at HI$\gamma$S, a new photon source being constructed at Duke\cite{23}. These experiments will have full photon and target polarization and will be a significant extension of the results we have at present. The estimated error for such an experiment running at HI$\gamma$S for $\approx 200$ hours of anticipated operation of the accelerator per data point is presented in Fig. 4 for $\text{Re}(E_0^+)$. There are equally small error bars estimated for the asymmetry measurement for unpolarized photons and a transversely polarized proton target. This experiment will allow us to extract $\text{Im}(E_0^+)$. Combining this with an independent measurement of the $\gamma p \rightarrow \pi^+ n$ cross section will allow us to extract $\beta$ at the few % level and measure the charge exchange scattering length $a_{\text{cex}}(\pi^+ n \rightarrow \pi^0 p)$ for the first time.

Although ChPT has been extremely successful in predicting the cross sections and the linearly polarized photon asymmetry in the $\gamma p \rightarrow \pi^0 p$ reaction there is a significant discrepancy with the $ep \rightarrow e' p \pi^0$ reaction data at $Q^2 = 0.05$ GeV$/c^2$ taken at Mainz\cite{25} shown in Fig. 5. It can be seen that the ChPT calculations\cite{26} do not agree with the data although the DMT dynamical model does\cite{20, 6}. This discrepancy is a potentially serious problem for ChPT which needs to be resolved. The reason is that the present calculations are $O(p^3)$ and it has been shown that to obtain agreement with the photo-pion data $O(p^4)$ calculations are needed.

The photo- and electro-pion $\gamma^* p \rightarrow \Delta$ reactions have been extensively used to study non-spherical amplitudes (shape) in the nucleon and $\Delta$ structure\cite{27, 28, 29}. This is studied by measuring the electric and Coulomb quadrupole amplitudes ($E2, C2$) in the predominantly magnetic dipole, quark spin flip ($M1$) $\gamma^* N \rightarrow \Delta$ amplitude. At low $Q^2$ the non-spherical pion cloud is a major contributor to this (for a review see\cite{27, 28, 29}). Figure 6 shows the Bates data\cite{30} for the transverse-longitudinal interference cross section $\sigma_{LT}$ at $Q^2 = 0.127$ GeV$/c^2$\cite{30}. This partial cross section is particularly sensitive to the Coulomb quadrupole C2 $\gamma^* N \rightarrow \Delta$ amplitude. This figure shows our best estimate of the difference between the electro-excitation $\Delta$ for the spherical case (the relatively flat, dark grey band) and the fit to the data which shows the C2 magnitude\cite{31, 32, 33}. The magnitude and $Q^2$ evolution of the Coulomb
Figure 4. The $\gamma p \rightarrow \pi^0 p$ reaction. Left panel: Polarized photon asymmetry $\Sigma$ versus angle at an average photon energy of 159.5 MeV$^{[17]}$. The solid (red) curve is ChPT, $O(p^3)$, the dotted (blue) curve is ChPT, $O(p^4)^{[12]}$. The dashed (green) curve is from dispersion theory$^{[24]}$. Right panel: Re$E_{0+}^{[15]}$ versus photon energy. The data points are from Mainz$^{[17]}$ and Saskatoon$^{[18]}$. The curves are from ChPT$^{[12]}$ and a unitary fit to the data$^{[11]}$. The two projected points from HI$\gamma$S are plotted at an arbitrary value (Re$E_{0+} = -1$) to show the anticipated statistical errors for 200 hours of running time per point. See text for discussion.

Figure 5. Cross section (left panel) and $LT'$ asymmetry (right panel) for the $ep \rightarrow e'\pi^0 p$ reaction at $Q^2 = 0.05$ GeV$^2/c^2$ versus $\Delta W$, the center of mass energy above threshold$^{[25]}$. See text for discussion.
quadrupole amplitude indicates that the quark models do not agree with experiment, but that models with pionic degrees of freedom do[6, 34], demonstrating that the crucial ingredient in the non-spherical amplitude at long range is the pion cloud. More recently there have been chiral-effective field theory calculations of this process[35, 36] which reinforce this observation. As was stated earlier, the presence of long range pionic effects in the non-spherical nucleon and Δ amplitudes is expected due to the spontaneous hiding of chiral symmetry and the associated p wave pion-nucleon interaction (see Eq. (1)).

3 Conclusions

We have shown that the classical isolated Δ resonance energy dependence (which is well known to be a p wave resonance) also depends on the weakness of the s wave amplitude. This behavior is expected on the basis of the spontaneous hiding of chiral symmetry in QCD: it is observed in the total cross sections for \(\pi^+/p\) scattering and in the \(\gamma p \rightarrow \pi^0 p\) reactions. It was shown that in the case of the \(\gamma p \rightarrow \pi^+ n\) reaction, where the Kroll-Ruderman theorem leads to a strong s wave production at threshold, that the energy dependence of the Δ resonance appears quite different.

In the well studied, near threshold \(\gamma^* p \rightarrow \pi^0 p\) reaction the agreement between O\( (p^4)\) ChPT calculations and experiment is excellent for the photon data but not so good for electroproduction at \(Q^2 = 0.05 \text{ GeV}^2/c^2\) where the calculations have only been carried out to O\( (p^3)\), indicating that further work is required. The pion cloud DMT model gives a reasonable description of all of the data. We have also mentioned further experiments which will test the theories.

Figure 6. \(\sigma_{LT}\) from the \(ep \rightarrow e' \pi^0 p\) reaction at \(Q^2 = 0.127 \text{ GeV}^2/c^2, W = 1232 \text{ MeV}\) (see text). The light grey curve is the fit to the data[30] and the relatively flat, dark grey curve shows the calculation for the spherical case, i.e. when the quadrupole transition amplitudes are set to zero[27, 31, 33].
in a more stringent fashion. These include photo-pion production experiments with transversely polarized targets which have the potential to measure $\pi N$ scattering in previously unexplored charge states ($\pi^0 n$ elastic scattering and charge exchange). If these can be performed with sufficient accuracy they will subject the theory to stringent tests. In addition, isospin conservation can be checked in a new way.

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Style File for Few-Body Systems

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Abstract. This is a short description of the class file FBSart and its class options that have been designed to generate a standard form for Few-Body Systems. It relies to some extend on the standard class article with class option size11 of I\TeX\ 2ε[2], the macro package based on the well-known type-setting program T\TeX\ [3], but a lot of new features have been included.

This paper describes how the class FBSart should be used by the author(s) so that further editorial efforts are minimized. If you are already familiar with I\TeX\ 2ε you can use most features of your preferred texts without changes of the input. The output, however, may look quite different.

1 Introduction

The class file FBSart is designed for coding contributions to Few-Body Systems Supplementum with I\TeX\ 2ε. The text provided along with this class will produce the desired layout. Authors are requested to adhere strictly to these instructions. The style file must not be changed!

The text output area will be 134 × 223 mm including page numbers.

Please refrain from using any I\TeX\ 2ε or T\TeX\ commands that affect the layout or formatting of your document (i.e., commands like \textheight, \vspace, \hoffset etc.). There may, nevertheless, be exceptional cases when some of them can be applied without problems.

2 Class Options

This is the first totally redesigned I\TeX\ 2ε class version for Few Body Systems. If you have serious reasons to use still I\TeX\ 2.09 look for the latest update of

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the old style with comments therein for compatibility mode. These are shipped with this version or may be retrieved via the web from:

http://electronix.kfunigraz.ac.at/cfbs

As package distinguishes between packages like amsfonts which load an extra file and options like secnumtab (see later in this section) which are usual finetuning parameters.

You may to get this class file as main class in the form \documentclass{FBSart}.

The style is designed only for 11pt output is always twoside and onecolumn, therefore some options of the standard article class will have no effect.

As additional packages like additional \textsc{.sty} files may be used, assumed to the extension of \texttt{.sty} files are symbolic \texttt{.sty} files for the fonts "Fraktur" and "Blackboard Bold".

\textsc{Few Body Systems} uses a special script font for some mathematical operators. You may substitute \texttt{\cal} for this script font.

If you want to include \textsc{PostScript} pictures you may also include e.g. \texttt{epsfig} (or any other graphic package) and use the commands defined therein.

For compatibility reasons the class will recognize all paper size options (without any layout effect!) and the options draft and final. There are four class option files (\texttt{.clo}): \texttt{FBSmath}, \texttt{ecsub}, \texttt{AMSsub}, and \texttt{FBSedit}, which will be explained later in this file. You may also specify the option all\texttt{.clo}, which will include all four option files. All option files can also be used by the \texttt{FBSsuppl} class.

Finally there are six options with regard to numbering styles.

1. Equations will be numbered consecutively throughout the whole document without any section reset. To change this setting use the option \texttt{secnumeq}. Then the counter will be set to zero in each new section and the number style will include the section number, e.g., (1.3).

2. Also numbering of tables and figures is default without section reference. If you have lots of floats in each section you can switch to the other numbering style by either \texttt{secnumfig} or \texttt{secnumtab}, respectively. In the appendices the default numbering includes the appendix number (A, B, C,..) and will be used in a similar way. To change the definitions for the appendices with the option \texttt{appnumeq}.

3. All numbers can be substituted by a specific label. For this purpose a label has to be given in front of the number, e.g., \texttt{\label{label} (1.3)}. To change to the other form select option \texttt{appnumfig} and/or \texttt{appnumtab}.

4. \textsc{LaTeX} 2\epsilon is case sensitive regarding the information in \texttt{ProvidePackage}, but not for file names.

5. A package \texttt{script} and the corresponding font files (\textsc{METAFONT} sources and precompiled packed font files) will be available.
| Option     | Short description | Requirements |
|------------|-------------------|--------------|
| secnumeq   | Changes to section numbering for equations |            |
| secnumfig  | Changes to section numbering for figures |            |
| secnumtab  | Changes to section numbering for tables |            |
| appnumeq   | Changes numbering for equations in appendices |            |
| appnumfig  | Changes numbering for figures in appendices |            |
| appnumtab  | Changes numbering for tables in appendices |            |
| FBSedit    | Editorial commands | FBSedit.clo |
| FBSmath    | Some mathematical extensions | FBSmath.clo |
| AMSsub     | Some AMS\TeX symbols in pure \LaTeX | AMSsub.clo |
| epsfig     | Allows some \special commands for PostScript figures |            |
| graphics   | Graphics package in combination with PostScript figures |            |

Be sure that you employ only allowed options, otherwise definition of dimensions in different styles may cause conflicts. You may use as many options and packages you need (Note: AMS\TeX packages are loaded after class options so you should not use \AMSsub and \amssymb).

Example:
```
\documentclass[secnumfig]{FBSart}
\usepackage{amssymb}
\usepackage{epsfig}
```

This loads all AMS\TeX definitions, allows inclusion of PostScript figures, and numbers equations after sections.

### 3 The Title Page

The title page of your manuscript is generated by the command \maketitle. This information displayed in the manuscript has to be generated in the preamble of the document using the command \begin{document}. As for article style there are the commands \author and \title. In addition the commands \institute and \instlist have been supplied.

The title of the paper should be entered using \title. The title should be correctly capitalized like any other heading text (see Section 5.6).

bm is part of the \LaTeX distribution since June 1997. It will be called by FBSart in the internal representation of a source.
The entry for \textbf{author} should contain all authors with their initials and their family names, with each author separated just by a comma (there should be no and, indicates <spacebar>).

Example:
\begin{itemize}
  \item \textbf{author}{W. Plessas}
  \item \textbf{author}{A.N. Mitra, I. Santhanam}
  \item \textbf{author}{B.M.K. Nefkens, S.D. Adrian, D.B. Barlow, F.D. Ottewell}
\end{itemize}

The institutes of the authors should be declared with the \texttt{\textbackslash{}institute} (or \texttt{\textbackslash{}instlist}) command.

A trivial example is:
\begin{itemize}
  \item \textbf{author}{J.J. Popiel, S.Y. Larsen}
  \item \textbf{institute}{Physics Department, Temple University, Philadelphia, PA 19122, USA}
\end{itemize}

If the authors are affiliated to more than one institution, the institutes will be shown in a numbered list. This list is generated by the command \texttt{\textbackslash{}instlist}. A reference to the institute(s) for a particular author, should be included inside the \texttt{\textbackslash{}author} command as \texttt{\textbackslash{}instnr{x}} with \texttt{x} being the actual institute number.

Any further comments like sponsorships, dedications, etc. should be included in footnotes via the \LaTeX{} command \texttt{\textbackslash{}thanks}. If you intend to use a second or further reference to a \texttt{\textbackslash{}thanks} command use \texttt{\textbackslash{}thanksnr{y}} wherein the number \texttt{y} refers to the “\texttt{y}th \texttt{\textbackslash{}thanks}.”

The institutes are entered in just one \texttt{\textbackslash{}instlist} command separated by \texttt{\textbackslash{}and}.

Example: Let us assume that the authors of \texttt{A. Alias}, \texttt{B. Brown} and \texttt{C. Complex} Alias belongs to institutes 2 and 3, Brown to institute 1 and 3, and 3, Alias wants to thank for some sponsorship and has to mention also his permanent institute. Brown wants to express a dedication and finally Complex has the same sponsor as Alias.

The correct input should be (the \% signs are used for comments in the source file; the text to follow until the end of line will be invisible in the document):
\begin{verbatim}
\author{A. Alias\instnr{2,3} \thanks{This work was sponsored by a generous fund}} \comma\thanks{Permanent address: Theoretical Division, University of Oz, 7 Dorothy Street, XX 77777, USA}, B. Brown\instnr{1,3} \thanks{Dedicated to A. Zweistein on the occasion of his 100th birthday}, C. Complex\instnr{1,3} \thanks{\% end of author list}
\end{verbatim}

A trivial example is:
\begin{verbatim}
\author{W. Plessas} \comma A. Mitra, I. Santhanam \comma B. Nefkens, S. Adrian, D. Barlow, F. Ottewell}
\end{verbatim}
A. Alias, B. Brown, C. Complex

1 Department of Mathematics, University of Jabberwocky, CC 1 23456, USA
2 Department of Theoretical Dynamics, Münchhausenstraße 1, D-31415 Oberlau, Germany
3 Department of Hydrodynamics, University of Paris, Rue de Seine 23, F-43666 Paris, France

Please note that in the command \instlist you need not supply the institute numbers!

Keywords in the \thanks argument like “Old address”, “Permanent address”, “On leave from”, “Email address” or something like these should be emphasised with \textit (e.g., \textit{Present address}) or \emph (e.g., \emph{Present address}). See also the example of the author of this article. If you have two or more consecutive \thanks for the same person the special comma may be useful to distinguish e.g. ∗∗∗ from ∗∗∗ (\instnr can handle “,” too). Alternatively a spacing command like \, may be used.

On the first page there appears also some editorial information: journal name, volume number, starting page, final page, and publication year.

Note: With \fbsedit you can change the starting page number (default is 1) and the volume number (default 0) but you can insert the counter changes right before \begin{document} in your text file if you do not need the other editorial commands.

The page number of the final page will be displayed as ?? at first run, and will then be redefined to the correct number by each new \LaTeX job. If there are floats at the end of the paper (see Sect. 5.2.1), i.e., even after the reference section, the macro will not work properly. In this case insert \clearpage before starting the bibliography.

The value for year will be supplied by \LaTeX (more precisely by your computer if the system time can be used by \LaTeX).

\textbf{Few Body Systems} allows for running titles and author information. These entries are generated by \runningauthor{running author} \runningtitle{running title} in the preamble or at least before \maketitle. If they are undefined an error message will occur on the screen during the \LaTeX job and on the output.

Author information should be supplied as in the list below.

\begin{itemize}
\item This work was sponsored by a generous fund.
\item Permanent address: Theoretical Division, University of Oz, 7 Dorothy Street, XX 77777, USA
\item Dedicated to A. Zweistein on the occasion of his 100th birthday
\item This is a just a test if footnotes are correctly redefined!
\end{itemize}
• If there is just one author \runningauthor contains the name like in \author (without all \thanks).

• If there are exactly two authors \runningauthor contains both names separated by "and", e.g. \runningauthor{A. B. First and C. D. Second}.

• If there are more than two authors \runningauthor contains just the name of the first author and "et al.", e.g. \runningauthor{A. B. First et al.}

The running title should preferably be the full title (as in \title). If the length of the title is beyond the scope of one line supply a short version (without trailing "...").

Example: The title \textit{Complete Analysis of the $\eta N S$-Wave Scattering-Length Values and Its Natural Limitations in Any Single-Resonance Model} might be shortened to \textit{Complete Analysis of the $\eta N S$-Wave Scattering-Length Values}.

4 This is a First-Order Headline

4.1 This Is a Second-Order Headline

4.1.1 This Is a Third-Order Headline

This is a fourth-order headline.

This is a fifth-order headline. You should use just the ordinary \LaTeX commands \section, \subsection, and \subsubsection as sectioning commands, even lower-order headlines are possible (with the \paragraph and \subparagraph commands) but not recommended! For \paragraph and \subparagraph you should not capitalize the heading. The dot (.) at the end of these headings will not be set by the macro. If you want also the sectioning commands with leading numbers use \addtocounter{secnumdepth}{1} or \addtocounter{secnumdepth}{2}, respectively.

For large papers also the sectioning command \part is defined as in the article class. This sectioning command resets counters in each part back to zero.

Special sections are reserved for the abstract \begin{abstract} and \end{abstract} and for acknowledgements \begin{acknowledge} and \end{acknowledge}.

Just write the corresponding text between these two environment delimiters.

The very special section \textit{Note Added in Proof} can also be obtained by an environment \begin{noteadded} and \end{noteadded}. You should insert this section before acknowledgements.

For the reference section use the \LaTeX environment \begin{thebibliography}{99} and \end{thebibliography}.

Actually you may wish to distinguish between \textit{Acknowledgement} and \textit{Acknowledgements}. For the latter form use the environment \acknowledgement.
It acts like \texttt{section*{References}}, but an “emptyness” check is also executed. This section should be the last section of your compuscript. The number 99 fixes the item separator space for your bibliography. If you have less than ten bibliography items apply 9 as argument, if there are more than 99 the argument should be 999.

If you want to add some appendices you have to insert the command \texttt{appendix}. All sectioning commands with the exception of \texttt{part} can be used therein. All counters are reset to zero and formulae (also tables and figures) will be numbered with reference to the appendix number, e.g., (A.1), (B.1), ...

If you have just one appendix, you may want to omit the name. This is easily done by typing the sequence

\texttt{appendix \section*{Appendix} \setcounter{section}{1}}

The last command ensures proper counting of equations, figures and tables in this special appendix. In appendices with names you need not include the word \texttt{Appendix}, also the section counter needs no special correction.

Do not forget the options \texttt{appnumeq}, \texttt{appnumfig}, and \texttt{appnumtab} to change the numbering style in appendices.

5 Editorial Commands

5.1 Preprint Format (FBSedit)

For proof reading an increased distance of consecutive lines will be helpful. To increase this distance you may use \texttt{widen} to reset it use \texttt{tighten}. These commands may be inserted before (after) a paragraph. It is possible to use these commands several times in your text if you want to widen the line distance just for some specific parts.

Both commands are defined in the class option \texttt{FBSedit}. Furthermore you can switch on and off grids for fine tuning your output. There are two sorts, one with spacing 5 mm (\texttt{gridmmon}) and the other with 10 pt (\texttt{gridpton}). You may switch between different grids in the same paper, turn it off with \texttt{gridmmonoff}, \texttt{gridptonoff} or (for both types) \texttt{nogrid}. The commands will be active for the next new page after their occurrence.

5.2 Tables and Figures

Tables and figures should be inserted as floats to ensure that
• these objects will be shown on the same page, if there is enough space left, or

• be inserted on another suitable place.

The environments \begin{figure} and \end{figure} (analogously for table) enable you to create floating objects.

5.2.1 Float Specifications

The same global structure is inherent in both environments. You may specify a preferred location for the float adding [location] as option for the \begin command. location is one or a combination of the following letters indicating different placement strategies

h h(ere), tries to insert the float just at the actual position (even in the middle of the page).

t t(op), tries to insert the float at the top of the actual page or any following pages

b b(ottom), tries to insert the float at the bottom of the actual page or any following pages

p p(age), uses a separate page for floats (there may be more than one floats on this page).

If you choose a combination, e.g. \begin{figure}[htb], \LaTeX 2ε takes the position that fits best according to its internal rules. If the selected option(s) is (are) not executable, option p is used. In this case all following floats are influenced since they will also be treated with option p! Therefore, selecting the option [h] is seldom satisfactory. It is recommended to choose either [htb] or [hbt].

It is useful to include some additional information (not the same as in the text) for floats. The command \caption[remark]{text} carries this information along with the float. The entry text will be the text shown on the float, remark is an optional text that is used for the float in the table of contents (i.e., the file .1of for figures and .1ot for tables). Especially for long text you should supply some short remark.

Captions for tables should be inserted above, captions for figures below the float body. After the \caption command you can use \label{labelinfo} to generate a reference label. A reference to this label has the form \ref{labelinfo} and will show the corresponding float number (with chapter reference if specified, but without brackets). labelinfo can be any text string without special characters.

As mentioned in Section 2 all floats are numbered consecutively in the compuscript if you take the standard settings. If you prefer section-specific numbering, employ the style options secnumtab and/or secnumfig. This settings will be reflected in the reference numbers for labels.

\footnote{Compared to the original article style the ratio of text to float space has been increased to ease proper placement of floats.}
5.2.2 The Body of a Table

The body of a table usually will consist in a tabular environment. You can use—almost—all specification specified in \LaTeX\ [1] or use extension Packages like supertab\[5].

**Table 2.** Entry specifiers for rows in the tabular environment, other tabular, and Few Body Systems specific commands

| Specifier | Short description |
|-----------|-------------------|
| l         | Flushleft entries |
| r         | Flushright entries|
| c         | Centered entries  |
| p{length} | Entries are put in a \texttt{parbox} with specified \texttt{length} |
| @{space}  | Removes interrow space and inserts \texttt{space}. Space can be a space token (\texttt{\hspace{...}}, ...) or any text you want as delimiter between two rows, e.g., “.” |
| *{num}{spec} | Repeats \texttt{num} times \texttt{spec} with any combination of the specifiers above |
| &         | Delimiter for entries |
| \\        | End character for tabular line |
| \\[space] | End character for tabular line and fills in additional vertical space with amount \texttt{space} |
| \hline    | Inserts a horizontal line (no proper spacing!) |
| \cline{a,b} | Inserts a horizontal line ranging from row \texttt{a} to \texttt{b} (no proper spacing!) |
| \firsthline | Inserts the first horizontal line (correct spacing) |
| \midhline | Inserts a horizontal line (correct spacing) |
| \lasthline | Inserts the last horizontal line (correct spacing) |
| \preline  | Inserts blank space before a \texttt{hline} or \texttt{cline} |
| \postline | Inserts blank space after a \texttt{hline} or \texttt{cline} |

Entry specifiers are shown in Table \[5.2.2\]. Some additions for Few Body Systems table style have been included. The main properties are

- There are no vertical lines.
- The spacing of text lines is increased.
- The tabular starts and ends with horizontal lines.
- The space below and above a horizontal line is enlarged.
- The caption width is the same as the tabular width!
- The text of the table is written with text height $\texttt{\footnotesize}$.

To ease the proper use of these limitations a lot of commands have to be supplied. For the spacing of text lines no action from the user is needed (handled by the style). The spacing of horizontal lines is a little bit more tricky. You have to apply special \texttt{hline}'s: \texttt{\firsthline}, \texttt{\midhline}, and \texttt{\lasthline}. These are
simple combinations of the spacing commands \preline and \postline with \hline\[7\]
\firstline = \hline\postline
\midline = \preline\hline\postline
\lastline = \preline\hline
The last line before \lastline has to be closed with \. If you want to use \cline combine the approbriate spacings (depending on the situation); if you have more than one \cline in the same line, add the spaces (if needed) just before the first and after the last \cline! For the last two items you just need three simple commands, \beforetab, \aftertab, and \captionaftertab[remark]{text}. The structure of the table environment has to be changed a little bit \beforetab has to be inserted between \begin{table} and \begin{tabular}{...} (The shrinking of the text will occur here\[8\]). \aftertab has to be inserted after \end{tabular} and \captionaftertab[remark]{text}.
\captionaftertab[remark]{text} is just the same as the “original” \caption. Although it is—in the text—situated after the tabular environment it will be displayed before it and with correct caption width. The delimiters [] are not optional, but the entry remark may still be empty.

For tabulars with varying row number \multicolumn{num}{spec}{text} can be used, which interprets num rows as one entry textit{text} with specifier spec.

5.2.3 The Body of a Figure

The body of a figure should contain the picture. \LaTeX\ allows to plot simple pictures with the picture environment, but technical plots are often beyond the scope of this tool. But some extensions like epic or eepic\[5\] may be sufficient.

For constituting a picture one has three quite different possibilities:

1. The plot is not too complex and can be generated with the \LaTeX\ picture commands (maybe with extensions). In this case insert the picture as body of the figure.

2. There are complex PostScript plots and a PostScript driver is used for \LaTeX output. Then one may use some \special commands defined in the epsfig for the inclusion of the plots. Include epsfig by inserting \usepackage{epsfig} in the preamble. A short list of commands can be found at the beginning of epsfig.

\[7\] These construction just works without any vertical lines! If you really have to use vertical lines you have to adapt the extra spacings!

\[8\] Some mathematical stuff, especially bold letteres, may not be available at this size. If you encounter some problems thereby you may use a larger fontsize, e.g. \small or \normalsize just for the critical items.
3. If the previous procedures are not applicable, it remains only to “paste in” the figures by hand. Specify the amount of space needed by inserting \vspace{\textit{space}} instead of the body of the figure.

Here are some examples for all three cases:

\begin{figure}[htb]
\vspace{70pt}
\caption{This is an example for an empty plot}
\end{figure}

\textbf{Figure 1.} This is an example for an empty plot

\begin{figure}[hbt]
\begin{picture}(112,112)
\put(0,0){\framebox(112,112){}}
\end{picture}
\caption{This is an example for a picture environment}
\end{figure}

\textbf{Figure 2.} This is an example for a \texttt{picture} environment

\begin{figure}[hbt]
\epsfig{file=figure.ps,width=100pt}
\caption{This is an example for a \texttt{PostScript} plot. The macro generates the corresponding \protect\texttt{special} calls for the printer driver}
\end{figure}
Uncomment these lines above if you have installed the package `epsfig` and the figure will be displayed.

5.2.4 Landscape Format Floats

If you want to supply some floats in landscape format, you have to include these pages in an extra file with appropriate page format. There you should specify the `\pagestyle{empty}` as standard page style. You cannot use the old counters, so insert the counter text manually. The `\caption` text should be `\small`, the float reference set in bold face.

In the main text you should use the macro `\emptyfloatpages{#1}{#2}{#3}` to fill in the missing information. `\emptyfloatpages` will increase the counters for figures by `#1` and for tables by `#2`. There will be `#3` empty pages generated in the main text (“empty” means empty with the exception of page numbers!).

If you want to try this command remove the heading `%` in the next line in this text file.

There will be no entries in the list of tables (`.lot`) and list of figures (`.lof`) files for these floats. But you may use reference labels:

`\addlabel{label}{t|f}{relative number}{relative page number}`.

Example: If you typed `\emptyfloatpages{3}{3}{2}`, i.e. 3 figures and 3 tables on 2 pages, you may reference the second table on the first page by e.g. `\ref{important}` after specifying `\addlabel{important}{t|2}{1}` (right after `\emptyfloatpages`!)

5.3 Mathematical Environments `FBSmath`

In LaTeX you can choose between different mathematical environments. For short formulae you can use the TeX primitive construction `$mathematical formula$`.

Example: Everybody knows Einstein’s famous law `$E=mc^2$`. Everybody knows Einstein’s famous law $E = mc^2$.

For displayed equations in separate lines there are three possibilities:

1. `\begin{displaymath} ... \end{displaymath}` for centered equations with no equation number.

2. `\begin{equation} ... \end{equation}` for centered equations with an equation number. Numbering is done according to Section [2].

3. `\begin{Equation}{#1} ... \end{Equation}` for centered equations with an equation “number” #1. Number can be any mathematical symbol or character string, e.g., ‘1’ or ‘’ (Do not forget the $ signs for mathematical symbols, the reference “number” is displayed in text mode!). The “number” will be enclosed in brackets as for normal equation numbers. The counter for equations will not be influenced by this command. (This environment is not standard LaTeX but part of FBSmath.)

Examples:
\begin{displaymath}
a^2+b^2 = c^2 \quad \text{(Pythagorean Formula)}
\end{displaymath}

\begin{equation}
a^n+b^n \ne c^n \quad \text{for } n > 2 \text{ and integers } a, b, c
\end{equation}

\begin{equation}
a^\varphi(n) \equiv 1 \pmod{n}
\end{equation}

In some cases you may want a set of equations as one “large” equation with “subequations”. The environment \begin{mathletters}... \end{mathletters} numbers equations with an additional letter and advances equation number counter just by one (FBSmath).

For aligned equations apply \begin{eqnarray}... \end{eqnarray}, which defines an array with structure rcl with equation numbers. If you want to omit some (but not all) numbers use \nonumber for this purpose. For no number at all take the “star” form eqnarray*.

For references to some equations you can insert labels in every environment that produces an equation number. Insert \label{eqlabel} after the \begin{...} command. References will be obtained by \ref{eqlabel}. If you insert the label in the mathletters environment just before the first equation you will get a reference to the whole set of equations (without trailing letters).

Example 1:

All Eqs. (\ref{alleq}) show the same structure
\begin{mathletters}
\label{alleq}
\begin{equation} E=m a^2 \end{equation}
\begin{equation} E=m b^2 \end{equation}
\begin{equation} \label{eqc} E=m c^2 \end{equation}
\end{mathletters}

but just Eq. (\ref{eqc}) is true.

All Eqs. (2) show the same structure

\begin{equation} E = ma^2 \end{equation}
\begin{equation} E = mb^2 \end{equation}
\begin{equation} E = mc^2 \end{equation}

but just Eq. (2c) is true.

Example 2:
Solving the linear system of equations (\ref{eqI}) and (\ref{eqII})
\begin{eqnarray}
x + y &=& a \label{eqI} \\
-x + y &=& b \label{eqII} \\
\Rightarrow 2y &=& a+b \nonumber \\
y &=& \frac{a+b}{2} \label{soly} \\
x &=& \frac{a-b}{2} \label{solx}.
\end{eqnarray}

one arrives at the solutions (\ref{solx}) for $x$ and (\ref{soly}) for $y$.

5.4 Notations for Mathematical, Physical, and Chemical Texts

In mathematical environments text is typeset in italics, except for mathematical functions (see the corresponding table in ref. [1]), which are displayed in roman letters.

In addition you should switch to roman (\mathrm) for input of the following categories (cf. also Section (6), especially for bold face material):

- Any new mathematical operator as rot, div, curl, . . . or any text in equations as, e.g., “const”. Also operators with greek letters, e.g. the Laplacian $\Delta$, should be roman.

- All chemical elements. If you need to supply atomic weight and element number use an empty pair of curled braces before the symbol, e.g., $^3_2\text{He}$ ⇒ $^3_2\text{He}$. You should not take the He outside the $'s otherwise a certain amount of blank space (\mathsurround) will be inserted.

- Physical units; e.g., pc, erg s$^{-1}$ K, cm$^{-3}$, W m$^{-2}$ Hz$^{-1}$, m kg s$^{-2}$ A$^{-2}$.

- For subscripts and superscripts in formulas where these are merely labels and not in themselves variables, e.g., $T_{\text{eff}}$ not $T_{\text{eff}}$, $T_K$ (where $K = \text{Kelvin}$) vs. $T_K$ (where $K=\text{kinetic energy}$)

- Digits.

All particle names as $e$, $p$, $d$, $\alpha$, $\Delta$ (nucleon resonance), . . . should be in italics.
5.5 Reference Style

References are quoted by numbers only. The numbers are in the sequence of their first citation in the document. In the text a reference will be shown with square brackets as, e.g., [7], and in the bibliography list there will be a numbered list (cf. the References of this document). The reference numbers are generated by \cite{biblabel}. Upon the first \LaTeX{} job each \cite will cause a warning because matching of the “requests” by \cite and the “answers” supplied with the \bibitem commands are carried along with the .aux file. So at least a second run is needed. If there are still warnings either you have forgotten an entry in the bibliography or you might have misspelled the \biblabel leading to a mismatch.

The entries in the \bibitem will have the form \bibitem{biblabel} reference text.

The reference text contains the author(s) with initials after the surname, separated by a colon, the abbreviated journal name, volume number in bold face, the first page, and the publication year in brackets. Book titles should be in roman font, followed by publication site, publishing house, and the publication year. If there are more than three authors use et al. (not in italics!).

Some typical examples are shown below. Have special care with the delimiters (.,:) of different entry types.

\begin{verbatim}
\bibitem{HMZ} Haftel, M. I., Mathelitsch, L., Zingl, H. F. K.:\ Phys. Rev. C23, 1285 (1980)
\bibitem{Petal} Plessas, W., et al.:\ Nuovo Cim. A35, 345 (1979)
\bibitem{QM} Messiah, A.: Quantum Mechanics. Amsterdam: North-Holland, 1964
\bibitem{MPEd} Mathelitsch, L., Plessas, W. (eds.):\ Substructures of Matter as Revealed with Electroweak Probes (Lecture Notes in Physics, vol. 236). Berlin: Springer, 1994
\bibitem{Alt} Altarelli, G.: In: Substructures of Matter as Revealed with Electroweak Probes (Lecture Notes in Physics, vol. 236), p. 37. Berlin: Springer, 1994
\bibitem{Private} N. N.: Private Communication (1997)
\bibitem{Prepr1} N. N.: Preprint UTP01/95 University of Graz 1995
\bibitem{two} Ashman, J., et al.:\ Phys. Lett. B206, 364 (1988);
\bibitem{Proc} Clajus, M., Nefkens, B., M.:\ Proc. \pi Newsletter, No. 7(H"ohler, G., Kluge, W., Nefkens, B., M. K., eds.), p. 76, 1992
\end{verbatim}
The output will look like these following lines (actually simulated, otherwise the bibliography of example2.tex might interfere with these items)

1. Haftel, M. I., Mathelitsch, L., Zingl, H. F. K.: Phys. Rev. C23, 1285 (1980)
2. Plessas, W., et al.: Nuovo Cim. A35, 345 (1979)
3. Messiah, A.: Quantum Mechanics. Amsterdam: North-Holland 1964
4. Mathelitsch, L., Plessas, W. (eds.): Substructures of Matter as Revealed with Electroweak Probes (Lecture Notes in Physics, vol. 236). Berlin: Springer 1994
5. Altarelli, G.: In: Substructures of Matter as Revealed with Electroweak Probes (Lecture Notes in Physics, vol. 236), p. 37. Berlin: Springer 1994
6. N. N.: Private Communication (1997)
7. N. N.: Preprint UTP01/95 University of Graz 1995
8. Kondo, Y., Saito, S.: Nucl. Phys. (to appear)
9. Goldman, T.: Phys. Rev. Lett. (in print)
10. Obersteiner, P.: Thesis. Univ. Graz 1994 (unpublished)
11. Ashman, J., et al.: Phys. Lett. B206, 364 (1988); Nucl. Phys. B328, 1 (1989)
12. Clajus, M., Nefkens, B. M. K.: In: \pi N Newsletter, No. 7 (Höhrler, G., Kluge, W., Nefkens, B. M. K., eds.), p. 76. 1992
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5.6 Editing the Input

All words in headings should be capitalized except for conjunctions, prepositions (e.g., on, of, by, and, or, but, from, ...) and definite and indefinite articles (the, a, an). Formula letters must be typeset as in the text.

5.6.1 Capitalization and Non-capitalization

- The following should always be capitalized:
  - Headings (see preceding Sect. 5.6)
  - Abbreviations and expressions in the text such as Fig(s)., Table(s), Sect(s), Chap(s), Theorem, Corollary, Definition etc. when used with numbers, e.g., Fig. 3, Table 1, Theorem 2.

  Please follow the special rules in Sect. 5.6.2 for referring to equations.

- The following should not be capitalized:
– The words figure(s), table(s), equation(s), theorem(s) in the text when used without an accompanying number
– Figure legends and table captions (except for names and abbreviations).
– The abbreviation ref., even when used with numbers, e.g., ref. [4].

5.6.2 Abbreviation of Words

• The following should be abbreviated when they appear in running text unless they come at the beginning of a sentence: Chap., Sect., Eq., Fig., ref.; for example, ... the results are depicted in Fig. 5. Figure 9 reveals that ...

Please note: An equation should usually be referred to by “Eq.” and its number in parentheses: e.g., Eq. (14). However, when the reference comes at the beginning of a sentence, the unabbreviated word “Equation” should be used: e.g., Equation (14) is very important. Follow the same style for references, however, with the abbreviation in lower-case letters “ref.”.

• If abbreviations of names or concepts are used throughout the text, they should be defined at first occurrence, e.g., Plurisubharmonic (PSH) Functions, Strong-Optimization (SOPT) Problem.

6 Additional Mathematical Commands

A lot of additional mathematical features have been supplied for the class \texttt{FBSart}. They are defined in the three class option files \texttt{FBSmath}, \texttt{AMSsub}, and \texttt{ecsub}. The two \texttt{-sub} options define just some symbols, which are part of other $\LaTeX$ packages.

Some commands have been redefined:

• Real part and imaginary part (\texttt{\textbackslash Re} and \texttt{\textbackslash Im}) will be displayed as \textit{Re} and \textit{Im} (instead of $\Re$ and $\Im$).

• All upper-case Greek symbols will be displayed in italics. For the Laplace operator \texttt{\textbackslash Laplace} ($\Delta$) and the unit of resistance \texttt{\textbackslash Ohm} ($\Omega$) roman upper-case Greek letters are used. If you need further roman upper-case Greek letters the standard commands with \texttt{rm} prefix will serve this job, e.g., \texttt{\textbackslash rmGamma} for $\Gamma$ (see Table [6]).

• For imaginary units $i$ and $j$ roman letters should be used. For this purpose the commands \texttt{\textbackslash jmath} and \texttt{\textbackslash imath} have been redefined in math mode. The old definitions can be obtained in math mode by using \texttt{\textbackslash inodot} ($i$) and \texttt{\textbackslash jnodot} ($j$) respectively.

• Vectors should be displayed in italic bold letters and not with arrows. Therefore \texttt{\textbackslash vec} is redefined to do this job, i.e. \texttt{\textbackslash vec} A will result in $\vec{A}$. If you need some arrows (e.g., for polarization notation) you can use

\footnote{This italic bold version for letters is generated by the package \texttt{bm}.}
\polarize for simple vector arrows (e.g., \polarize e becomes \vec{e}). If you need tensor arrows (\leftrightarrow) or reversed arrows (\leftarrow) you can do this with the commands \texttt{\tensor} and \texttt{\loarrow}. (Do not mix these commands with \polarize because the arrows are of different size. Consequently use \texttt{\roarrow} instead of \polarize in combination with the other arrow accents.)

A new accent in math mode is a tilde below the specified letter. Usage: \texttt{\utilde{a}} for \(a \tilde{}\). To ensure italic notation in mathematical formulae you should not use \texttt{\mathbf} in math mode but \texttt{\bm}. It can be used for ordinary letters, greek letters, super- and subscripts.

Example: $\bm{e}^{\imath \bm{\pi}}+1=0$.

If you cannot use the \texttt{AMS\TeX} symbols, some of the relations have been prepared for pure \texttt{LATEX} (option \texttt{AMSsub}). The names of the symbols are identical with their \texttt{AMS\TeX} versions. If you include the \texttt{amssymb} package the \texttt{AMS\TeX} symbols will be taken by default.

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|l|l|l|}
\hline
Name & Gamma & Delta & Theta & Lambda & Xi & Pi \\
\hline
Italic version & \(\Gamma\) & \(\Delta\) & \(\Theta\) & \(\Lambda\) & \(\Xi\) & \(\Pi\) \\
Roman version & \(\Gamma\) & \(\Delta\) & \(\Theta\) & \(\Lambda\) & \(\Xi\) & \(\Pi\) \\
\hline
Name & Sigma & Upsilon & Phi & Psi & Omega \\
\hline
Italic version & \(\Sigma\) & \(\Upsilon\) & \(\Phi\) & \(\Psi\) & \(\Omega\) \\
Roman version & \(\Sigma\) & \(\Upsilon\) & \(\Phi\) & \(\Psi\) & \(\Omega\) \\
\hline
\end{tabular}
\caption{Comparison of italic and roman upper-case Greek letters}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|l|}
\hline
Name & Symbol & Name & Symbol \\
\hline
square & \(\square\) & leftrightarrows & \(\Leftarrow\) \\
& & leqq & \(\leqq\) \\
& & geqq & \(\geqq\) \\
& & gtrless & \(\gtrless\) \\
\hline
\end{tabular}
\caption{Additional \texttt{AMSS\TeX} symbols for pure \texttt{LATEX} (names without leading backslash)}
\end{table}

In addition to the standard \texttt{LATEX} and \texttt{AMSS\TeX} symbols five more symbols have been defined for common use.

- The symbol \texttt{\openone II} can be used in math mode only (defined in \texttt{FBS-math}, not part of any \texttt{AMS} package!).
- The symbols \texttt{\prom} and \texttt{\Prom}. In order to produce per cent signs matching these per mille signs also the commands \texttt{\perc} and \texttt{\Perc}.
have been defined (in ecmath). The new ec-fonts (and tc-fonts) supply the per mille sign and also a small zero digit to be used in combination with %.

A few more examples for all those definitions with \verb"\" translation:

\[ \int_V \Phi^* \Psi dV = 1 = \Delta \Gamma^* \Upsilon \]

\begin{mathletters}
\begin{equation}
\vec{i} \times \vec{j} = \vec{k}
\end{equation}
\begin{equation}
\vec{a} = \vec{\alpha} \bullet \vec{\beta}
\end{equation}
\end{mathletters}

\begin{math}
\text{If } z = a + ib, \text{ then } \text{Re}(z) = a \text{ and } \text{Im}(z) = b
\end{math}

\begin{Equation}{\diamondsuit}
(A \times B) \cdot (C \times D) = (A \cdot C) (B \cdot D) - (A \cdot D) (B \cdot C)
\end{Equation}

This is a test for strange labels as in (\ref{test}).

\textbf{a}(x,y)=\textbf{\Psi}(\textbf{\xi},\textbf{\eta})\times\textbf{\Phi}
\[ a(x, y) = \Psi(\xi, \eta) \times \Phi \]  

(10)

If you have \texttt{AMSTeX} installed you may uncomment the lines

\begin{verbatim}
\usepackage{amsfonts}
\usepackage{amssymb}
\input{exam2AMS}
\end{verbatim}

and insert the \texttt{usepackage}'s in the preamble to have a list of all symbols available.

**Appendix**

In case \texttt{AMSTeX} is installed on your computer, the packages \texttt{amsfonts} or \texttt{amssymb} will allow you to load \texttt{AMS} fonts or \texttt{AMSB} fonts and symbols with FBSart.

**A.1 \texttt{AMS} Fonts Notations**

The \texttt{AMS} fonts were developed by the American Mathematical Society and are made available free of charge by the \texttt{AMS}. The \texttt{METAFONT} source files can be obtained, as are precompiled .pk files.

**A.2 Using \texttt{amsfonts}**

The \texttt{amsfonts} class option provides the \texttt{\frak} and \texttt{\mathbb} fonts and will also use the extra Computer Modern fonts from the \texttt{AMS} in order to provide better access to bold math characters at smaller sizes and in super- and subscripts.

With the \texttt{AMS} fonts installed and employing either the \texttt{amsfonts} or \texttt{amssymb} (see Section A.3 below) class option, the \texttt{\mathfrak} and \texttt{\mathbb} commands are available. \texttt{\mathfrak} switches to the \texttt{AMS} Fraktur font, while \texttt{\mathbb} switches to the so-called “Blackboard Bold” font. Only uppercase letters are available in Blackboard Bold, and there is no bold version of this font. Fraktur has both uppercase and lowercase letters, and also a bold version is available. Here are the letters “ABCxyz” from \texttt{\mathfrak}: ABCxyz. And here are the letters “CRZN” from \texttt{\mathbb}: CRZN.

Here is some mathematics with superscripts and \texttt{\mathfrak}.

\[ E = mc^2 \pi. \]

To use \texttt{\bf} we have to switch to \texttt{\normalfont}, otherwise no bold fonts are available.

normal \( E = mc^{2\pi} \) and bold \( \mathbf{E} = mc^{2\pi} \)

**A.3 Using \texttt{amssymb}**

The \texttt{amssymb} class option defines many extra symbols present in the \texttt{AMS} fonts. These symbols and their names are shown in the following tables.

Be aware that no bold versions are available for any of the symbols in this section. A lot of \texttt{TeX}'s memory will be blocked by defining these names. Therefore you should select this option with care.
Table A.1. Extra symbols available with amssymb

| Symbol | Command |
|--------|---------|
| \digamma | \varkappa |
| \beth | \gimel |
| \hbar | \hslash |
| \varnothing | \blacklozenge |
| \exists | \complement |
| \Finv | \maltese |
| \bigstar | \blacktriangle |
| \centerdot | \dashrightarrow |

Table A.2. Binary operators available with the amssymb

| Symbol | Command |
|--------|---------|
| \dotplus | \ltimes |
| \times | \smallsetminus |
| \veebar | \curlyvee |
| \Cap | \cup |
| \rightthreetimes | \circledast |
| \multimap | \multimap |
| \dashrightarrow | \dashrightarrow |

Table A.3. Extra arrows available with the amssymb

| Symbol | Command |
|--------|---------|
| \leftrightharpoons | \leftrightharpoons |
| \leftarrowtail | \rightarrowtail |
| \Lsh | \Rsh |
| \restriction | \restriction |
| \rightleftharpoons | \rightleftharpoons |
| \leftrightsquigarrow | \leftrightsquigarrow |
| \dashleftarrow | \dashleftarrow |
| \nLeftarrow | \nLeftarrow |
| \nrightarrow | \nrightarrow |
| \nRightarrow | \nRightarrow |
Table A.4. Binary relations available with the \texttt{amssymb}
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