Single particle, cluster, and collective excitation modes of ^{13}C below E_x=10 MeV

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Abstract. The elastic and inelastic scattering of deuterons from ^{13}C are registered in the wide range of angles at laboratory energies 14.5 MeV and 18 MeV. Data on the differential cross sections are treated within the both Optical Model and Coupled-Channels method. A new set of Optical Potential parameters are found. An analyses for the $d+^{13}$ C* nuclear reactions are carried out for the J^π excitation levels of ^{13}C*: $\frac{1}{2}^+$, $\frac{3}{2}^-$, $\frac{5}{2}{}_2^+$, $\frac{5}{2}^-$, $\frac{1}{2}^-$, and $\frac{3}{2}^-$. The first excitation band, $\frac{1}{2}^+$, having a nature of single particle excitation, is used for extracting the Spectroscopic Amplitudes of $\langle^{12}\mathrm{C}|^{13}\mathrm{C}\rangle$ and $\langle^{12}\mathrm{C}|^{13}\mathrm{C}^*\ \frac{1}{2}^+\rangle$ overlaps. A comparison of taken spectroscopic informations with the values by other authors are presented. The deformation parameters of the rest excited states are listed.

Keywords: nuclear reactions, halo structure, coupled channels, inelastic scattering

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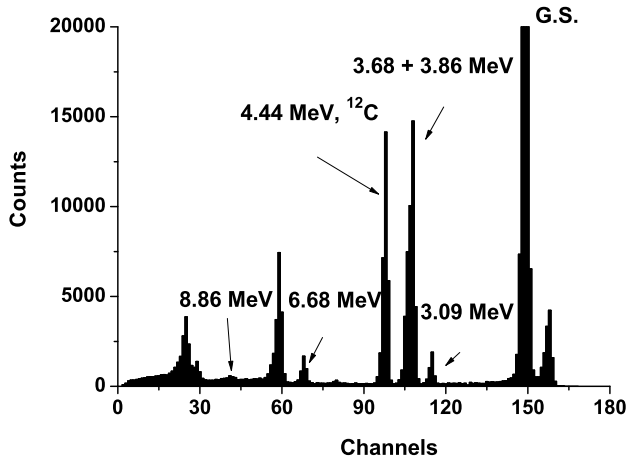

Figure 1. The spectra of registered deuteron particles at the angle of 38° as the result of d + ^{13}C nuclear reaction.

1. Introduction

2. Experimental method

The experiment has been carried out in the cyclotron U-150M of the Institute of nuclear physics located in Almaty, the Republic of Kazakhstan. The energy of the d beam was chosen to be at the laboratory energy of 14.5 MeV. The scattered ions of deuteron were measured at the wide rage angles 10° - 100°.

For the purpose of the identification of reaction products the ΔE–E method was used. The telescope detectors ΔE were taken as the silicon surface barrier detectors by ORTEC®. The thickness of the detectors ΔE was 50 μm, while the detectors E had the thickness of 1 mm. The thin films of ^{13}C with the 80% isotopic enrichment were extracted by means of the electron-beam sputtering technique. It was possible to make the films self-supporting and to obtain their surface density up to 150 μg/cm^2. Two collimators with a diameter of 2 mm were used in order to get the optimal focusing on the target.

In Fig. 1 the spectrum of the total deposited energy is shown measured at the θ_{lab}=38° for the detected d.

3. Coupled-Channels Method

Consider a nuclear reaction of inelastic scattering $a + A \to a' + A^*$. We denote entrance and exit channels as α and α' correspondingly. The inelastic channel α' is induced with an excitation of the target nucleus A. The Schrödinger equation for this system with the energy E is

$$H\Psi = E\Psi, \tag{1}$$

where the Hamiltonian H, which may be written as

$$H = H_\alpha + T_\alpha + V_\alpha. \tag{2}$$

Here, H_a and H_A are the internal Hamiltonians of colliding nuclei, T_α is the kinetic energy operator, and V_α is the interaction potential of the $a + A$ system. The corresponding total wave function Ψ may be represented as

$$\Psi = \phi_\alpha(\mathbf{r})\chi_\alpha(\mathbf{R}) + \phi_{\alpha'}(\mathbf{r})\chi_{\alpha'}(\mathbf{R}). \tag{3}$$

Here, ϕ_α and $\phi_{\alpha'}$ are the wave functions of ground and excited states, χ_α and $\chi_{\alpha'}$ are the scattering wave functions of α and α' channels. The wave functions of the ground $\phi_{\alpha'}$ and the excited $\phi_{\alpha'}$ states satisfy the Schrödinger equation in the following

$$H_\alpha\phi_\alpha(\mathbf{r}) = \epsilon_\alpha\phi_\alpha(\mathbf{r}) \tag{4}$$

$$H_\alpha\phi_{\alpha'}(\mathbf{r}) = \epsilon_{\alpha'}\phi_{\alpha'}(\mathbf{r}), \tag{5}$$

Multiplying Eqs. (1) from left by the conjugated wave function Eqs. (3) one may get the coupled equations as follow

$$\left(E - \epsilon_\alpha - K_\alpha - U_{\alpha\alpha}\right)\chi_\alpha\left(R\right) = U_{\alpha\alpha'}\chi_{\alpha'}\left(R\right) \tag{6}$$

$$\left(E - \epsilon_{\alpha'} - K_{\alpha'} - U_{\alpha'\alpha'}\right)\chi_{\alpha'}\left(R\right) = U_{\alpha\alpha'}\chi_\alpha\left(R\right) \tag{7}$$

Here, $U_{\alpha\alpha'}$ is the coupling potential. Depending on the considering model of excitation it may have different representation.

The nature of excitation in the α' channel would be collective. In the framework of *the Collective Model* the coupling potential $U_{\alpha\alpha'}$ may be considered .

4. Introduction: file preparation and submission

The `iopart` LaTeX 2_ε article class file is provided to help authors prepare articles for submission to IOP Publishing journals. This document gives advice on preparing your submission, and specific instructions on how to use `iopart.cls` to follow this advice. You do not have to use `iopart.cls`; articles prepared using any other common class and style files can also be submitted. It is not necessary to mimic the appearance of a published article.

The advice on LaTeX file preparation in this document applies to the journals listed in table 1. If your journal is not listed please go to the journal website via `http://iopscience.iop.org/journals` for specific submission instructions.

Any special submission requirements for the journals are indicated with footnotes in table 1. Journals which require references in a particular format will need special care if you are using BibTeX, and you might need to use a `.bst` file that gives slightly non-standard output in order to supply any extra information required. It is not necessary to give references in the exact style of references used in published articles, as long as all of the required information is present.

Table 1. Journals to which this document applies, and macros for the abbreviated journal names in `iopart.cls`. Macros for other journal titles are listed in appendix A.

Short form of journal title	Macro name	Short form of journal title	Macro name
2D Mater.	`\TDM`	Mater. Res. Express	`\MRE`
Biofabrication	`\BF`	Meas. Sci. Technol.[c]	`\MST`
Bioinspir. Biomim.	`\BB`	Methods Appl. Fluoresc.	`\MAF`
Biomed. Mater.	`\BMM`	Modelling Simul. Mater. Sci. Eng.	`\MSMSE`
Class. Quantum Grav.	`\CQG`	Nucl. Fusion	`\NF`
Comput. Sci. Disc.	`\CSD`	New J. Phys.	`\NJP`
Environ. Res. Lett.	`\ERL`	Nonlinearity[a,b]	`\NL`
Eur. J. Phys.	`\EJP`	Nanotechnology	`\NT`
Inverse Problems	`\IP`	Phys. Biol.[c]	`\PB`
J. Breath Res.	`\JBR`	Phys. Educ.[a]	`\PED`
J. Geophys. Eng.[d]	`\JGE`	Physiol. Meas.[c,d,e]	`\PM`
J. Micromech. Microeng.	`\JMM`	Phys. Med. Biol.[c,d,e]	`\PMB`
J. Neural Eng.[c]	`\JNE`	Plasma Phys. Control. Fusion	`\PPCF`
J. Opt.	`\JOPT`	Phys. Scr.	`\PS`
J. Phys. A: Math. Theor.	`\jpa`	Plasma Sources Sci. Technol.	`\PSST`
J. Phys. B: At. Mol. Opt. Phys.	`\jpb`	Rep. Prog. Phys.[e]	`\RPP`
J. Phys: Condens. Matter	`\JPCM`	Semicond. Sci. Technol.	`\SST`
J. Phys. D: Appl. Phys.	`\JPD`	Smart Mater. Struct.	`\SMS`
J. Phys. G: Nucl. Part. Phys.	`\jpg`	Supercond. Sci. Technol.	`\SUST`
J. Radiol. Prot.[a]	`\JRP`	Surf. Topogr.: Metrol. Prop.	`\STMP`
Metrologia	`\MET`	Transl. Mater. Res.	`\TMR`

[a]UK spelling is required; [b]MSC classification numbers are required; [c]titles of articles are required in journal references; [d]Harvard-style references must be used (see section 9); [e]final page numbers of articles are required in journal references.

Also note that there is an incompatibility between `amsmath.sty` and `iopart.cls` which cannot be completely worked around. If your article relies on commands in `amsmath.sty` that are not available in `iopart.cls`, you may wish to consider using a different class file.

Whatever journal you are submitting to, please look at recent published articles (preferably articles in your subject area) to familiarize yourself with the features of the journal. We do not demand that your LaTeX file closely resembles a published article—a generic 'preprint' appearance of the sort commonly seen on `arXiv.org` is fine—but your submission should be presented in a way that makes it easy for the referees to form an opinion of whether it is suitable for the journal. The generic advice in this document—on what to include in an abstract, how best to present complicated mathematical expressions, and so on—applies whatever class file you are using.

4.1. What you will need to supply

Submissions to our journals are handled via the ScholarOne web-based submission system. When you submit a new article to us you need only submit a PDF of your

article. When you submit a revised version, we ask you to submit the source files as well. Upon acceptance for publication we will use the source files to produce a proof of your article in the journal style.

4.1.1. Text. When you send us the source files for a revised version of your submission, you should send us the LaTeX source code of your paper with all figures read in by the source code (see section 12.1). Articles can be prepared using almost any version of TeX or LaTeX, not just LaTeX with the class file `iopart.cls`. You may split your LaTeX file into several parts, but please show which is the 'master' LaTeX file that reads in all of the other ones by naming it appropriately. The 'master' LaTeX file must read in all other LaTeX and figure files from the current directory. *Do not read in files from a different directory, e.g.* `\includegraphics{/figures/figure1.eps}` *or* `\include{../usr/home/smith/myfiles/macros.tex}`*—we store submitted files all together in a single directory with no subdirectories.*

- **Using LaTeX packages.** Most LaTeX 2_ε packages can be used if they are available in common distributions of LaTeX 2_ε; however, if it is essential to use a non-standard package then any extra files needed to process the article must also be supplied. Try to avoid using any packages that manipulate or change the standard LaTeX fonts: published articles use fonts in the Times family, but we prefer that you use LaTeX default Computer Modern fonts in your submission. The use of LaTeX 2.09, and of plain TeX and variants such as AMSTeX is acceptable, but a complete PDF of your submission should be supplied in these cases.

4.1.2. Figures. Figures should ideally be included in an article as encapsulated PostScript files (see section 12.1) or created using standard LaTeX drawing commands. Please name all figure files using the guidelines in section 4.3.2. We accept submissions that use pdfTeX to include PDF or bitmap figures, but please ensure that you send us a PDF that uses PDF version 1.4 or lower (to avoid problems in the ScholarOne system). You can do this by putting `\pdfminorversion=4` at the very start of your TeX file.

All figures should be included within the body of the text at an appropriate point or grouped together with their captions at the end of the article. A standard graphics inclusion package such as `graphicx` should be used for figure inclusion, and the package should be declared in the usual way, for example with `\usepackage{graphicx}`, after the `\documentclass` command. Authors should avoid using special effects generated by including verbatim PostScript code in the submitted LaTeX file. Wherever possible, please try to use standard LaTeX tools and packages.

4.1.3. References. You can produce your bibliography in the standard LaTeX way using the `\bibitem` command. Alternatively you can use BibTeX: our preferred `.bst` styles are:

- For the numerical (Vancouver) reference style we recommend that authors use `unsrt.bst`; this does not quite follow the style of published articles in our journals but this is not a problem. Alternatively `iopart-num.bst` created by Mark A Caprio produces a reference style that closely matches that in published articles. The file is available from `http://ctan.org/tex-archive/biblio/bibtex/contrib/iopart-num/` .
- For alphabetical (Harvard) style references we recommend that authors use the `harvard.sty` in conjunction with the `jphysicsB.bst` BibTeX style file. These, and accompanying documentation, can be downloaded from `http://www.ctan.org/tex-archive/macros/latex/contrib/harvard/`. Note that the `jphysicsB.bst` bibliography style does not include article titles in references to journal articles. To include the titles of journal articles you can use the style `dcu.bst` which is included in the `harvard.sty` package. The output differs a little from the final journal reference style, but all of the necessary information is present and the reference list will be formatted into journal house style as part of the production process if your article is accepted for publication.

Please make sure that you include your `.bib` bibliographic database file(s) and any `.bst` style file(s) you have used.

4.2. Copyrighted material and ethical policy

If you wish to make use of previously published material for which you do not own the copyright then you must seek permission from the copyright holder, usually both the author and the publisher. It is your responsibility to obtain copyright permissions and this should be done prior to submitting your article. If you have obtained permission, please provide full details of the permission granted—for example, copies of the text of any e-mails or a copy of any letters you may have received. Figure captions must include an acknowledgment of the original source of the material even when permission to reuse has been obtained. Please read our ethical policy before writing your article.

4.3. Naming your files

4.3.1. General. Please name all your files, both figures and text, as follows:

- Use only characters from the set a to z, A to Z, 0 to 9 and underscore (_).
- Do not use spaces or punctuation characters in file names.
- Do not use any accented characters such as á, ê, ñ, ö.
- Include an extension to indicate the file type (e.g., `.tex`, `.eps`, `.txt`, etc).
- Use consistent upper and lower case in filenames and in your LaTeX file. If your LaTeX file contains the line `\includegraphics{fig1.eps}` the figure file must be called `fig1.eps` and not `Fig1.eps` or `fig1.EPS`. If you are on a Unix system, please ensure that there are no pairs of figures whose names differ only in capitalization,

such as `fig_2a.eps` and `fig_2A.eps`, as Windows systems will be unable to keep the two files in the same directory.

When you submit your article files, they are manipulated and copied many times across multiple databases and file systems. Including non-standard characters in your filenames will cause problems when processing your article.

4.3.2. Naming your figure files. In addition to the above points, please give each figure file a name which indicates the number of the figure it contains; for example, `figure1.eps`, `figure2a.eps`, etc. If the figure file contains a figure with multiple parts, for example figure 2(a) to 2(e), give it a name such as `figure2a_2e.eps`, and so forth.

4.4. How to send your files

Please send your submission via the ScholarOne submission system. Go to the journal home page, and use the 'Submit an article' link on the right-hand side.

5. Preparing your article

5.1. Sample coding for the start of an article

The code for the start of a title page of a typical paper in the `iopart.cls` style might read:

```
\documentclass[12pt]{iopart}
\begin{document}
\title[The anomalous magnetic moment of the
neutrino]{The anomalous magnetic moment of the
neutrino and its relation to the solar neutrino problem}

\author{P J Smith$^1$, T M Collins$^2$,
R J Jones$^3$\footnote{Present address:
Department of Physics, University of Bristol, Tyndalls Park Road,
Bristol BS8 1TS, UK.} and Janet Williams$^3$}

\address{$^1$ Mathematics Faculty, Open University,
Milton Keynes MK7~6AA, UK}
\address{$^2$ Department of Mathematics,
Imperial College, Prince Consort Road, London SW7~2BZ, UK}
\address{$^3$ Department of Computer Science,
University College London, Gower Street, London WC1E~6BT, UK}
\ead{williams@ucl.ac.uk}

\begin{abstract}
...
\end{abstract}
```

```
\keywords{magnetic moment, solar neutrinos, astrophysics}
\submitto{\jpg}
\maketitle
```

At the start of the LaTeX source code please include commented material to identify the journal, author, and (if you are sending a revised version or a resubmission) the reference number that the journal has given to the submission. The first non-commented line should be `\documentclass[12pt]{iopart}` to load the preprint class file. The normal text will be in the Computer Modern 12pt font. It is possible to specify 10pt font size by passing the option `[10pt]` to the class file. Although it is possible to choose a font other than Computer Modern by loading external packages, this is not recommended.

The article text begins after `\begin{document}`. Authors of very long articles may find it convenient to separate their article into a series of LaTeX files each containing one section, and each of which is called in turn by the primary file. The files for each section should be read in from the current directory; please name the primary file clearly so that we know to run LaTeX on this file.

Authors may use any common LaTeX `.sty` files. Authors may also define their own macros and definitions either in the main article LaTeX file or in a separate `.tex` or `.sty` file that is read in by the main file, provided they do not overwrite existing definitions. It is helpful to the production staff if complicated author-defined macros are explained in a LaTeX comment. The article class `iopart.cls` can be used with other package files such as those loading the AMS extension fonts `msam` and `msbm`, which provide the blackboard bold alphabet and various extra maths symbols as well as symbols useful in figure captions. An extra style file `iopams.sty` is provided to load these packages and provide extra definitions for bold Greek letters.

5.2. Double-column layout

The `iopart.cls` class file produces single-column output by default, but a two-column layout can be obtained by using `\documentclass[10pt]` at the start of the file and `\ioptwocol` after the `\maketitle` command. Two-column output will begin on a new page (unlike in published double-column articles, where the two-column material starts on the same page as the abstract).

In general we prefer to receive submissions in single-column format even for journals published in double-column style; however, the `\ioptwocol` option may be useful to test figure sizes and equation breaks for these journals. When setting material in two columns you can use the asterisked versions of LaTeX commands such as `\begin{figure*} ... \end{figure*}` to set figures and tables across two columns. If you have any problems or any queries about producing two-column output, please contact us at `submissions@iop.org`.

Table 2. Types of article defined in the `iopart.cls` class file.

Command	Article type
`\title{#1}`	Paper (no surtitle on first page)
`\ftc{#1}`	Fast Track Communication
`\review{#1}`	Review
`\topical{#1}`	Topical Review
`\comment{#1}`	Comment
`\note{#1}`	Note
`\paper{#1}`	Paper (no surtitle on first page)
`\prelim{#1}`	Preliminary Communication
`\rapid{#1}`	Rapid Communication
`\letter{#1}`	Letter to the Editor
`\article{#1}{#2}`	Other articles (use this for any other type of article; surtitle is whatever is entered as `#1`)

6. The title and abstract page

If you use `iopart.cls`, the code for setting the title page information is slightly different from the normal default in LaTeX. If you are using a different class file, you do not need to mimic the appearance of an `iopart.cls` title page, but please ensure that all of the necessary information is present.

6.1. Titles and article types

The title is set using the command `\title{#1}`, where `#1` is the title of the article. The first letter of the title should be capitalized with the rest in lower case. The title appears in bold case, but mathematical expressions within the title may be left in light-face type.

If the title is too long to use as a running head at the top of each page (apart from the first) a short form can be provided as an optional argument (in square brackets) before the full title, i.e. `\title[Short title]{Full title}`.

For article types other than papers, `iopart.cls` has a generic heading `\article[Short title]{TYPE}{Full title}` and some specific definitions given in table 2. In each case (apart from Letters to the Editor and Fast Track Communications) an optional argument can be used immediately after the control sequence name to specify the short title; where no short title is given, the full title will be used as the running head. Not every article type has its own macro—use `\article` for any not listed. A full list of the types of articles published by a journal is given in the submission information available via the journal home page. The generic heading could be used for articles such as those presented at a conference or workshop, e.g.

```
\article[Short title]{Workshop on High-Energy Physics}{Title}
```

Footnotes to titles may be given by using `\footnote{Text of footnote.}` immediately after the title. Acknowledgment of funding should be included in the acknowledgments section rather than in a footnote.

6.2. Authors' names and addresses

For the authors' names type `\author{#1}`, where `#1` is the list of all authors' names. Western-style names should be written as initials then family name, with a comma after all but the last two names, which are separated by 'and'. Initials should *not* be followed by full stops. First (given) names may be used if desired. Names in Chinese, Japanese and Korean styles should be written as you want them to appear in the published article. Authors in all IOP Publishing journals have the option to include their names in Chinese, Japanese or Korean characters in addition to the English name: see appendix B for details.

If the authors are at different addresses a superscripted number, e.g. [1], `$^1$`, should be used after each name to reference the author to his/her address. If an author has additional information to appear as a footnote, such as a permanent address, a normal LaTeX footnote command should be given after the family name and address marker with this extra information.

The authors' affiliations follow the list of authors. Each address is set by using `\address{#1}` with the address as the single parameter in braces. If there is more than one address then the appropriate superscripted number, followed by a space, should come at the start of the address.

E-mail addresses are added by inserting the command `\ead{#1}` after the postal address(es) where `#1` is the e-mail address. See section 5.1 for sample coding. For more than one e-mail address, please use the command `\eads{\mailto{#1}, \mailto{#2}}` with `\mailto` surrounding each e-mail address. Please ensure that, at the very least, you state the e-mail address of the corresponding author.

6.3. The abstract

The abstract follows the addresses and should give readers concise information about the content of the article and indicate the main results obtained and conclusions drawn. It should be self-contained—there should be no references to figures, tables, equations, bibliographic references etc. It should be enclosed between `\begin{abstract}` and `\end{abstract}` commands. The abstract should normally be restricted to a single paragraph of around 200 words.

6.4. Subject classification numbers

We no longer ask authors to supply Physics and Astronomy Classification System (PACS) classification numbers. For submissions to *Nonlinearity* we ask that you should supply Mathematics Subject Classification (MSC) codes. MSC numbers are included after the abstract using `\ams{#1}`.

The command `\submitto{#1}` can be inserted, where `#1` is the journal name written in full or the appropriate control sequence as given in table 1. This command is not essential to the running of the file and can be omitted.

6.5. Keywords

Keywords are required for all submissions. Authors should supply a minimum of three (maximum seven) keywords appropriate to their article as a new paragraph starting `\noindent{\it Keywords\/}:` after the end of the abstract.

6.6. Making a separate title page

To keep the header material on a separate page from the body of the text insert `\maketitle` (or `\newpage`) before the start of the text. If `\maketitle` is not included the text of the article will start immediately after the abstract.

7. The text

7.1. Sections, subsections and subsubsections

The text of articles may be divided into sections, subsections and, where necessary, subsubsections. To start a new section, end the previous paragraph and then include `\section` followed by the section heading within braces. Numbering of sections is done *automatically* in the headings: sections will be numbered 1, 2, 3, etc, subsections will be numbered 2.1, 2.2, 3.1, etc, and subsubsections will be numbered 2.3.1, 2.3.2, etc. Cross references to other sections in the text should, where possible, be made using labels (see section 10) but can also be made manually. See section 8.7 for information on the numbering of displayed equations. Subsections and subsubsections are similar to sections but the commands are `\subsection` and `\subsubsection` respectively. Sections have a bold heading, subsections an italic heading and subsubsections an italic heading with the text following on directly.

```
\section{This is the section title}
\subsection{This is the subsection title}
```

The first section is normally an introduction, which should state clearly the object of the work, its scope and the main advances reported, with brief references to relevant results by other workers. In long papers it is helpful to indicate the way in which the paper is arranged and the results presented.

Footnotes should be avoided whenever possible and can often be included in the text as phrases or sentences in parentheses. If required, they should be used only for brief notes that do not fit conveniently into the text. The use of displayed mathematics in footnotes should be avoided wherever possible and no equations within a footnote should be numbered. The standard LaTeX macro `\footnote` should be used. Note that in `iopart.cls` the `\footnote` command produces footnotes indexed by a variety of different symbols, whereas in published articles we use numbered footnotes. This is not a problem: we will convert symbol-indexed footnotes to numbered ones during the production process.

7.2. Acknowledgments

Authors wishing to acknowledge assistance or encouragement from colleagues, special work by technical staff or financial support from organizations should do so in an unnumbered 'Acknowledgments' section immediately following the last numbered section of the paper. In `iopart.cls` the command `\ack` sets the acknowledgments heading as an unnumbered section.

Please ensure that you include all of the sources of funding and the funding contract reference numbers that you are contractually obliged to acknowledge. We often receive requests to add such information very late in the production process, or even after the article is published, and we cannot always do this. Please collect all of the necessary information from your co-authors and sponsors as early as possible.

7.3. Appendices

Technical detail that it is necessary to include, but that interrupts the flow of the article, may be consigned to an appendix. Any appendices should be included at the end of the main text of the paper, after the acknowledgments section (if any) but before the reference list. If there are two or more appendices they should be called Appendix A, Appendix B, etc. Numbered equations will be in the form (A.1), (A.2), etc, figures will appear as figure A1, figure B1, etc and tables as table A1, table B1, etc.

The command `\appendix` is used to signify the start of the appendices. Thereafter `\section`, `\subsection`, etc, will give headings appropriate for an appendix. To obtain a simple heading of 'Appendix' use the code `\section*{Appendix}`. If it contains numbered equations, figures or tables the command `\appendix` should precede it and `\setcounter{section}{1}` must follow it.

7.4. Some matters of style

It will help the readers if your article is written in a clear, consistent and concise manner. During the production process we will try to make sure that your work is presented to its readers in the best possible way without sacrificing the individuality of your writing. Some recommended points to note, however, are the following. These apply to all of the journals listed in table 1.

(i) Authors are often inconsistent in the use of 'ize' and 'ise' endings. We recommend using '-ize' spellings (diagonalize, renormalization, minimization, etc) but there are some common exceptions to this, for example: devise, promise and advise.

(ii) The words table and figure should be written in full and **not** abbreviaged to tab. and fig. Do not include 'eq.', 'equation' etc before an equation number or 'ref.' 'reference' etc before a reference number.

Please check your article carefully for accuracy, consistency and clarity before submission. Remember that your article will probably be read by many people whose

native language is not English and who may not be aware of many of the subtle meanings of words or idiomatic phases present in the English language. It therefore helps if you try to keep sentences as short and simple as possible. If you are not a native English speaker, please ask a native English speaker to read your paper and check its grammar.

8. Mathematics

8.1. Two-line constructions

The great advantage of LaTeX over other text processing systems is its ability to handle mathematics of almost any degree of complexity. However, in order to produce an article suitable for publication both within a print journal and online, authors should exercise some restraint on the constructions used. Some equations using very small characters which are clear in a preprint style article may be difficult read in a smaller format.

For simple fractions in the text the solidus `/`, as in $\lambda/2\pi$, should be used instead of `\frac` or `\over`, using parentheses where necessary to avoid ambiguity, for example to distinguish between $1/(n-1)$ and $1/n-1$. Exceptions to this are the proper fractions $\frac{1}{2}$, $\frac{1}{3}$, $\frac{3}{4}$, etc, which are better left in this form. In displayed equations horizontal lines are preferable to solidi provided the equation is kept within a height of two lines. A two-line solidus should be avoided where possible; the construction $(\ldots)^{-1}$ should be used instead. For example use:

$$\frac{1}{M_{\mathrm{a}}}\left(\int_0^\infty \mathrm{d}\omega\ \frac{|S_o|^2}{N}\right)^{-1} \qquad \text{instead of} \qquad \frac{1}{M_{\mathrm{a}}}\Big/\int_0^\infty \mathrm{d}\omega\ \frac{|S_o|^2}{N}.$$

8.2. Roman and italic in mathematics

In mathematics mode LaTeX automatically sets variables in an italic font. In most cases authors should accept this italicization. However, there are some cases where it is preferable to use a Roman font; for instance, a Roman d for a differential d, a Roman e for an exponential e and a Roman i for the square root of -1. To accommodate this and to simplify the typing of equations, `iopart.cls` provides some extra definitions. `\rmd`, `\rme` and `\rmi` now give Roman d, e and i respectively for use in equations, e.g. $\mathrm{i}x\mathrm{e}^{2x}\mathrm{d}x/\mathrm{d}y$ is obtained by typing `$\rmi x\rme^{2x}\rmd x/\rmd y$`.

Certain other common mathematical functions, such as cos, sin, det and ker, should appear in Roman type. Standard LaTeX provides macros for most of these functions (in the cases above, `\cos`, `\sin`, `\det` and `\ker` respectively); `iopart.cls` also provides additional definitions for Tr, tr and O (`\Tr`, `\tr` and `\Or`, respectively).

Subscripts and superscripts should be in Roman type if they are labels rather than variables or characters that take values. For example in the equation

$$\epsilon_m = -g\mu_{\mathrm{n}}Bm$$

m, the z component of the nuclear spin, is italic because it can have different values whereas n is Roman because it is a label meaning nuclear (μ_{n} is the nuclear magneton).

8.3. Displayed equations in double-column journals

Authors should bear in mind that all mathematical formulae in double-column journals will need to fit into the width of a single column. You may find it helpful to use a two-column layout (such as the two-column option in `iopart.cls`) in your submission so that you can check the width of equations.

8.4. Special characters for mathematics

Bold italic characters can be used in our journals to signify vectors (rather than using an upright bold or an over arrow). To obtain this effect when using `iopart.cls`, use `\bi{#1}` within maths mode, e.g. $\boldsymbol{ABCdef}$. Similarly, in `iopart.cls`, if upright bold characters are required in maths, use `\mathbf{#1}` within maths mode, e.g. $\mathbf{XYZabc}$. The calligraphic (script) uppercase alphabet is obtained with `\mathcal{AB}` or `\cal{CD}` ($\mathcal{ABCD}$).

The American Mathematical Society provides a series of extra symbol fonts to use with LaTeX and packages containing the character definitions to use these fonts. Authors wishing to use Fraktur or Blackboard Bold can include the appropriate AMS package (e.g. `amsgen.sty`, `amsfonts.sty`, `amsbsy.sty`, `amssymb.sty`) with a `\usepackage` command or add the command `\usepackage{iopams}` which loads the four AMS packages mentioned above and also provides definitions for extra bold characters (all Greek letters and some other additional symbols).

The package `iopams.sty` uses the definition `\boldsymbol` in `amsbsy.sty` which allows individual non-alphabetical symbols and Greek letters to be made bold within equations. The bold Greek lowercase letters are obtained with the commands `\balpha` ... `\bomega` (but note that bold eta is `\bfeta` rather than `\beta`) and the capitals with commands `\bGamma` ... `\bOmega`. Bold versions of the following symbols are predefined in `iopams.sty`: bold partial `\bpartial`, bold 'ell' `\bell`, bold imath `\bimath`, bold jmath `\bjmath`, bold infinity `\binfty`, bold nabla `\bnabla`, bold centred dot `\bdot`. Other characters are made bold using `\boldsymbol{\symbolname}`.

Please do not use the style file `amsmath.sty` (part of the AMSTeX package) in conjunction with `iopart.cls`. This will result in several errors. To make use of the macros defined in `amsmath.sty`, `iopart.cls` provides the file `setstack.sty` which reproduces the following useful macros from `amsmath.sty`:

```
\overset \underset \sideset \substack \boxed   \leftroot
\uproot  \dddot    \ddddot  \varrow   \harrow
```

If the mathematical notation that you need is best handled in `amsmath.sty` you might want to consider using an article class other than `iopart.cls`. We accept submissions using any class or style files.

Table 3 lists some other macros for use in mathematics with a brief description of their purpose.

Table 3. Other macros defined in `iopart.cls` for use in maths.

Macro	Result	Description
`\fl`		Start line of equation full left
`\case{#1}{#2}`	$\frac{\#1}{\#2}$	Text style fraction in display
`\Tr`	Tr	Roman Tr (Trace)
`\tr`	tr	Roman tr (trace)
`\Or`	O	Roman O (of order of)
`\tdot{#1}`	$\dddot{x}$	Triple dot over character
`\lshad`	$[\![$	Text size left shadow bracket
`\rshad`	$]\!]$	Text size right shadow bracket

8.5. Alignment of displayed equations

The normal style for aligning displayed equations in our published journal articles is to align them left rather than centre. The `iopart.cls` class file automatically does this and indents each line of a display. In `iopart.cls`, to make any line start at the left margin of the page, add `\fl` at start of the line (to indicate full left).

Using the `eqnarray` environment equations will naturally be aligned left and indented without the use of any ampersands for alignment, see equations (8) and (9)

$$\alpha + \beta = \gamma^2, \tag{8}$$

$$\alpha^2 + 2\gamma + \cos\theta = \delta. \tag{9}$$

This is the normal equation style for our journals.

Where some secondary alignment is needed, for instance a second part of an equation on a second line, a single ampersand is added at the point of alignment in each line (see (10) and (11)).

$$\alpha = 2\gamma^2 + \cos\theta + \frac{XY\sin\theta}{X + Y\cos\theta} \tag{10}$$

$$= \delta\theta PQ\cos\gamma. \tag{11}$$

Two points of alignment are possible using two ampersands for alignment (see (12) and (13)). Note in this case extra space `\qquad` is added before the second ampersand in the longest line (the top one) to separate the condition from the equation.

$$\alpha = 2\gamma^2 + \cos\theta + \frac{XY\sin\theta}{X + Y\cos\theta} \qquad \theta > 1 \tag{12}$$

$$= \delta\theta PQ\cos\gamma \qquad \theta \leq 1. \tag{13}$$

For a long equation which has to be split over more than one line the first line should start at the left margin, this is achieved by inserting `\fl` (full left) at the start of the line. The use of the alignment parameter `&` is not necessary unless some secondary alignment is needed.

$$\alpha + 2\gamma^2 = \cos\theta + \frac{XY\sin\theta}{X + Y\cos\theta} + \frac{XY\sin\theta}{X - Y\cos\theta} + + \left(\frac{XY\sin\theta}{X + Y\cos\theta}\right)^2$$

$$+\left(\frac{XY\sin\theta}{X-Y\cos\theta}\right)^2. \tag{14}$$

The plain TEX command `\eqalign` can be used within an `equation` environment to obtain a multiline equation with a single centred number, for example

$$\begin{aligned}&\alpha+\beta=\gamma^2\\&\alpha^2+2\gamma+\cos\theta=\delta.\end{aligned} \tag{15}$$

During the production process we will break equations as appropriate for the page layout of the journal. If you are submitting to a double-column journal and wish to review how your equations will break, you may find the double-column layout described in section 5.2 useful.

8.6. Miscellaneous points

The following points on the layout of mathematics apply whichever class file you use.

Exponential expressions, especially those containing subscripts or superscripts, are clearer if the notation exp(...) is used, except for simple examples. For instance $\exp[\mathrm{i}(kx-\omega t)]$ and $\exp(z^2)$ are preferred to $\mathrm{e}^{\mathrm{i}(kx-\omega t)}$ and e^{z^2}, but e^x is acceptable.

Similarly the square root sign $\sqrt{}$ should only be used with relatively simple expressions, e.g. $\sqrt{2}$ and $\sqrt{a^2+b^2}$; in other cases the power 1/2 should be used; for example, $[(x^2+y^2)/xy(x-y)]^{1/2}$.

It is important to distinguish between $\ln = \log_{\mathrm{e}}$ and $\lg = \log_{10}$. Braces, brackets and parentheses should be used in the following order: $\{[(\ )]\}$. The same ordering of brackets should be used within each size. However, this ordering can be ignored if the brackets have a special meaning (e.g. if they denote an average or a function).

Decimal fractions should always be preceded by a zero: for example 0.123 **not** .123. For long numbers use thin spaces after every third character away from the position of the decimal point, unless this leaves a single separated character: e.g. 60 000, 0.123 456 78 but 4321 and 0.7325.

Equations should be followed by a full stop (periods) when at the end of a sentence.

8.7. Equation numbering and layout in `iopart.cls`

LATEX provides facilities for automatically numbering equations and these should be used where possible. Sequential numbering (1), (2), etc, is the default numbering system although in `iopart.cls`, if the command `\eqnobysec` is included in the preamble, equation numbering by section is obtained, e.g. (2.1), (2.2), etc. Equation numbering by section is used in appendices automatically when the `\appendix` command is used, even if sequential numbering has been used in the rest of the article. Refer to equations in the text using the equation number in parentheses. It is not normally necessary to include the word equation before the number; and abbreviations such as eqn or eq should not be used. In `iopart.cls`, there are alternatives to the standard `\ref` command that you might find useful—see table 4.

Sometimes it is useful to number equations as parts of the same basic equation. This can be accomplished in `iopart.cls` by inserting the commands `\numparts` before the equations concerned and `\endnumparts` when reverting to the normal sequential numbering. For example using `\numparts \begin{eqnarray} ... \end{eqnarray} \endnumparts`:

$$\begin{aligned} T_{11} &= (1+P_{\mathrm{e}})I_{\uparrow\uparrow} - (1-P_{\mathrm{e}})I_{\uparrow\downarrow}, && (16a)\\ T_{-1-1} &= (1+P_{\mathrm{e}})I_{\downarrow\downarrow} - (1-P_{\mathrm{e}})I_{\uparrow\downarrow}, && (16b)\\ S_{11} &= (3+P_{\mathrm{e}})I_{\downarrow\uparrow} - (3-P_{e})I_{\uparrow\uparrow}, && (16c)\\ S_{-1-1} &= (3+P_{\mathrm{e}})I_{\uparrow\downarrow} - (3-P_{\mathrm{e}})I_{\downarrow\downarrow}. && (16d) \end{aligned}$$

Equation labels within the `\eqnarray` environment will be referenced as subequations, e.g. (16*a*).

8.8. Miscellaneous extra commands for displayed equations

The `\cases` command has been amended slightly in `iopart.cls` to increase the space between the equation and the condition. Equation (17) demonstrates simply the output from the `\cases` command

$$X = \begin{cases} 1 & \text{for } x \geq 0 \\ -1 & \text{for } x < 0 \end{cases} \qquad (17)$$

To obtain text style fractions within displayed maths the command `\case{#1}{#2}` can be used instead of the usual `\frac{#1}{#2}` command or `{#1 \over #2}`.

When two or more short equations are on the same line they should be separated by a 'qquad space' (`\qquad`), rather than `\quad` or any combination of `\,`, `\>`, `\;` and `\ `.

9. Referencing

Two different styles of referencing are in common use: the Harvard alphabetical system and the Vancouver numerical system. All journals to which this document applies allow the use of either the Harvard or Vancouver system, except for *Physics in Medicine and Biology* and *Physiological Measurement* for which authors *must* use the Harvard referencing style (with the titles of journal articles given, and final page numbers given).

9.1. Harvard (alphabetical) system

In the Harvard system the name of the author appears in the text together with the year of publication. As appropriate, either the date or the name and date are included within parentheses. Where there are only two authors both names should be given in the text; if there are more than two authors only the first name should appear followed by '*et al*' (which can be obtained in `iopart.cls` by typing `\etal`). When two or more

references to work by one author or group of authors occur for the same year they should be identified by including a, b, etc after the date (e.g. 2012a). If several references to different pages of the same article occur the appropriate page number may be given in the text, e.g. Kitchen (2011, p 39).

The reference list at the end of an article consists of an unnumbered 'References' section containing an alphabetical listing by authors' names. References with the same author list are ordered by date, oldest first. The reference list in the preprint style is started in `iopart.cls` by including the command `\section*{References}` and then `\begin{harvard}`. Individual references start with `\item[]` and the reference list is completed with `\end{harvard}`. There is also a shortened form of the coding: `\section*{References}` and `\begin{harvard}` can be replaced by the single command `\References`, and `\end{harvard}` can be shortened to `\endrefs`.

9.2. Vancouver (numerical) system

In the Vancouver system references are numbered sequentially throughout the text. The numbers occur within square brackets and one number can be used to designate several references. A numerical reference list in the `iopart` style is started by including the command `\section*{References}` and then `\begin{thebibliography}{<num>}`, where `<num>` is the largest number in the reference list (or any other number with the same number of digits). The reference list gives the references in numerical order, individual references start with `\bibitem{label}`. The list is completed by `\end{thebibliography}`. Short forms of the commands are again available: `\Bibliography{<num>}` can be used at the start of the references section and `\endbib` at the end.

A variant of this system is to use labels instead of numbers within square brackets, in this case references in the list should start with `\bibitem[label-text]`. This method is allowed for all journals that accept numerical references.

9.3. BibTeX

If you are using BibTeX, see the earlier section 4.1.3 for information on what `.bst` file to use. The output that you get will differ slightly from that specified in the rest of this section, but this is not a problem as long as all the relevant information is present.

9.4. References, general

A complete reference should provide the reader with enough information to locate the item concerned. Up to ten authors may be given in a particular reference; where there are more than ten only the first should be given followed by '*et al*'. If you are using BibTeX and the `.bst` file that you are using includes more than 10 authors, do not worry about this: we can correct this during the production process. Abbreviate a journal name only

in accordance with the journal's own recommendations for abbreviation—if in doubt, leave it unabbreviated.

The terms *loc. cit.* and *ibid.* should not be used. Unpublished conferences and reports should generally not be included in the reference list if a published version of the work exists. Articles in the course of publication should include the article title and the journal of publication, if known. A reference to a thesis submitted for a higher degree may be included if it has not been superseded by a published paper—please state the institution where the work was submitted.

The basic structure of a reference in the reference list is the same in both the alphabetical and numerical systems, the only difference being the code at the start of the reference. Alphabetical references are preceded by `\item[]`, numerical by `\bibitem{label}` or just `\item` to generate a number or `\nonum` where a reference is not the first in a group of references under the same number.

Note that footnotes to the text should not be included in the reference list, but should appear at the bottom of the relevant page by using the `\footnote` command.

9.5. References to journal articles

The following guidance applies if you are producing your reference list 'by hand'; that is, without the help of BibTeX. See section 4.1.3 for BibTeX help.

Article references in published articles in our journals contain three changes of font: the authors and date appear in Roman type, the journal title in italic, the volume number in bold and the page numbers in Roman again. A typical journal entry would be:

Spicer P E, Nijhoff F W and van der Kamp P H 2011 *Nonlinearity* **24** 2229

which would be obtained by typing, within the references environment

```
\item[] Spicer P E, Nijhoff F W and van der Kamp P H 2011 {\it Nonlinearity}
{\bf 24} 2229
```

Features to note are the following.

(i) The authors should be in the form of surname (with only the first letter capitalized) followed by the initials with no periods after the initials. Authors should be separated by a comma except for the last two which should be separated by 'and' with no comma preceding it.

(ii) The year of publication follows the authors and is not in parentheses.

(iii) Titles of journal articles can also be included (in Roman (upright) text after the year). Article titles are required in reference lists for *Inverse Problems, Journal of Neural Engineering, Measurement Science and Technology, Physical Biology, Physics in Medicine and Biology* and *Physiological Measurement*.

(iv) The journal is in italic and is abbreviated. If a journal has several parts denoted by different letters the part letter should be inserted after the journal in Roman type (e.g. *Phys. Rev.* A). `iopart.cls` includes macros for abbreviated titles of all

journals handled by IOP Publishing (see table A3) and some other common titles (table A5).

(v) The volume number is bold; the page number is Roman. Both the initial and final page numbers should be given where possible—note that for *Reports on Progress in Physics*, *Physiological Measurement* and *Physics in Medicine and Biology* the final page number is *required*. The final page number should be in the shortest possible form and separated from the initial page number by an en rule (--), e.g. 1203–14.

(vi) Where there are two or more references with identical authors, the authors' names should be repeated for the second and subsequent references. Each individual publication should be presented as a separate reference, although in the numerical system one number can be used for several references. This facilitates linking in the online journal.

9.5.1. Article numbering. Many journals now use article-numbering systems that do not fit the conventional *year-journal-volume-page numbers* pattern. Some examples are:

[1] Carlip S and Vera R 1998 *Phys. Rev.* D **58** 011345
[2] Davies K and Brown G 1997 *J. High Energy Phys.* JHEP12(1997)002
[3] Hannestad S 2005 *J. Cosmol. Astropart. Phys.* JCAP02(2005)011
[4] Hilhorst H J 2005 *J. Stat. Mech.* L02003
[5] Gundlach C 1999 *Liv. Rev. Rel.* 1994-4

The website of the journal you are citing should state the correct format for citations.

9.6. Preprint references

Preprints may be referenced but if the article concerned has been published in a peer-reviewed journal, that reference should take precedence. If only a preprint reference can be given, it is helpful to include the article title. Examples are:

[1] Neilson D and Choptuik M 2000 *Class. Quantum Grav.* **17** 761 (arXiv:gr-qc/9812053)
[2] Sundu H, Azizi K, Süngü J Y and Yinelek N 2013 Properties of $D^*_{s2}(2573)$ charmed-strange tensor meson arXiv:1307.6058

For preprints added to arXiv.org after April 2007 it is not necessary to include the subject area, however this information can be included in square brackets after the number if desired, e.g.

[1] Sundu H, Azizi K, Süngü J Y and Yinelek N 2013 Properties of $D^*_{s2}(2573)$ charmed-strange tensor meson arXiv:1307.6058 [hep-ph]

9.7. References to books, conference proceedings and reports

References to books, proceedings and reports are similar, but have only two changes of font. The authors and date of publication are in Roman, the title of the book is in italic, and the editors, publisher, town of publication and page number are in Roman. A typical reference to a book and a conference paper might be

Dorman L I 1975 *Variations of Galactic Cosmic Rays* (Moscow: Moscow State University Press) p 103

Caplar R and Kulisic P 1973 *Proc. Int. Conf. on Nuclear Physics (Munich)* vol 1 (Amsterdam: North-Holland/American Elsevier) p 517

which would be obtained by with the code

```
\item[] Dorman L I 1975 {\it Variations of Galactic Cosmic Rays}
(Moscow: Moscow State University Press) p~103
\item[] Caplar R and Kulisic P 1973 {\it Proc. Int. Conf. on Nuclear
Physics (Munich)} vol~1 (Amsterdam: North-Holland/American
Elsevier) p~517
```

Features to note are the following.

(i) Book titles are in italic and should be spelt out in full with initial capital letters for all except minor words. Words such as Proceedings, Symposium, International, Conference, Second, etc should be abbreviated to Proc., Symp., Int., Conf., 2nd, respectively, but the rest of the title should be given in full, followed by the date of the conference and the town or city where the conference was held. For laboratory reports the laboratory should be spelt out wherever possible, e.g. *Argonne National Laboratory Report*.

(ii) The volume number, for example, vol 2, should be followed by the editors, if any, in the form ed A J Smith and P R Jones. Use *et al* if there are more than two editors. Next comes the town of publication and publisher, within brackets and separated by a colon, and finally the page numbers preceded by p if only one number is given or pp if both the initial and final numbers are given.

(iii) If a book is part of a series (for examples, *Springer Tracts in Modern Physics*), the series title and volume number is given in parentheses after the book title. Whereas for an individual volume in a multivolume set, the set title is given first, then the volume title.

Morse M 1996 Supersonic beam sources *Atomic Molecular and Optical Physics* (*Experimental Methods in the Physical Sciences* vol 29) ed F B Dunning and R Hulet (San Diego, CA: Academic)

Fulco C E, Liverman C T and Sox H C (eds) 2000 *Gulf War and Health* vol 1 *Depleted Uranium, Pyridostigmine Bromide, Sarin, and Vaccines* (Washington, DC: The National Academies Press)

10. Cross-referencing

The facility to cross reference items in the text is very useful when composing articles as the precise form of the article may be uncertain at the start and revisions and amendments may subsequently be made. LaTeX provides excellent facilities for doing cross-referencing and these can be very useful in preparing articles.

10.1. References

Cross referencing is useful for numeric reference lists because, if it is used, adding another reference to the list does not then involve renumbering all subsequent references. It is not necessary for referencing in the Harvard system where the final reference list is

alphabetical and normally no other changes are necessary when a reference is added or deleted. When using LaTeX, two passes (under certain circumstances, three passes) are necessary initially to get the cross references right but once they are correct a single run is usually sufficient provided an `.aux` file is available and the file is run to the end each time. If the reference list contains an entry `\bibitem{label}`, this command will produce the correct number in the reference list and `\cite{label}` will produce the number within square brackets in the text. `label` may contain letters, numbers or punctuation characters but must not contain spaces or commas. It is also recommended that the underscore character _ is not used in cross referencing. Thus labels of the form `eq:partial`, `fig:run1`, `eq:dy'`, etc, may be used. When several references occur together in the text `\cite` may be used with multiple labels with commas but no spaces separating them; the output will be the numbers within a single pair of square brackets with a comma and a thin space separating the numbers. Thus `\cite{label1,label2,label4}` would give [1, 2, 4]. Note that no attempt is made by the style file to sort the labels and no shortening of groups of consecutive numbers is done. Authors should therefore either try to use multiple labels in the correct order, or use a package such as `cite.sty` that reorders labels correctly.

The numbers for the cross referencing are generated in the order the references appear in the reference list, so that if the entries in the list are not in the order in which the references appear in the text then the numbering within the text will not be sequential. To correct this change the ordering of the entries in the reference list and then rerun the LaTeX file *twice*. Please ensure that all references resolve correctly: check the `.log` file for undefined or multiply-defined citations, and check that the output does not contain question marks that indicate unresolved references.

10.2. Equation numbers, sections, subsections, figures and tables

Labels for equation numbers, sections, subsections, figures and tables are all defined with the `\label{label}` command and cross references to them are made with the `\ref{label}` command.

Any section, subsection, subsubsection, appendix or subappendix command defines a section type label, e.g. 1, 2.2, A2, A1.2 depending on context. A typical article might have in the code of its introduction 'The results are discussed in section~`\ref{disc}`.' and the heading for the discussion section would be:

```
\section{Results}\label{disc}
```

Labels to sections, etc, may occur anywhere within that section except within another numbered environment. Within a maths environment labels can be used to tag equations which are referred to within the text.

In addition to the standard `\ref{<label>}`, in `iopart.cls` the abbreviated forms given in table 4 are available for reference to standard parts of the text.

Table 4. Alternatives to the normal references command `\ref` available in `iopart.cls`, and the text generated by them. Note it is not normally necessary to include the word equation before an equation number except where the number starts a sentence. The versions producing an initial capital should only be used at the start of sentences.

Reference	Text produced
`\eref{<label>}`	(`<num>`)
`\Eref{<label>}`	Equation (`<num>`)
`\fref{<label>}`	figure `<num>`
`\Fref{<label>}`	Figure `<num>`
`\sref{<label>}`	section `<num>`
`\Sref{<label>}`	Section `<num>`
`\tref{<label>}`	table `<num>`
`\Tref{<label>}`	Table `<num>`

11. Tables and table captions

Tables are numbered serially and referred to in the text by number (table 1, etc, **not** tab. 1). Each table should have an explanatory caption which should be as concise as possible. If a table is divided into parts these should be labelled (*a*), (*b*), (*c*), etc but there should be only one caption for the whole table, not separate ones for each part.

In the preprint style the tables may be included in the text or listed separately after the reference list starting on a new page.

11.1. The basic table format

The standard form for a table in `iopart.cls` is:

```
\begin{table}
\caption{\label{label}Table caption.}
\begin{indented}
\item[]\begin{tabular}{@{}llll}
\br
Head 1&Head 2&Head 3&Head 4\\
\mr
1.1&1.2&1.3&1.4\\
2.1&2.2&2.3&2.4\\
\br
\end{tabular}
\end{indented}
\end{table}
```

Points to note are:

(i) The caption comes before the table. It should have a period at the end.

(ii) Tables are normally set in a smaller type than the text. The normal style is for tables to be indented. This is accomplished by using `\begin{indented}` ...

Table 5. A simple example produced using the standard table commands and `\lineup` to assist in aligning columns on the decimal point. The width of the table and rules is set automatically by the preamble.

A	*B*	*C*	*D*	*E*	*F*	*G*
23.5	60	0.53	−20.2	−0.22	1.7	14.5
39.7	−60	0.74	−51.9	−0.208	47.2	146
123.7	0	0.75	−57.2	—	—	—
3241.56	60	0.60	−48.1	−0.29	41	15

`\end{indented}` and putting `\item[]` before the start of the tabular environment. Omit these commands for any tables which will not fit on the page when indented.

(iii) The default is for columns to be aligned left and adding `@{}` omits the extra space before the first column.

(iv) Tables have only horizontal rules and no vertical ones. The rules at the top and bottom are thicker than internal rules and are set with `\br` (bold rule). The rule separating the headings from the entries is set with `\mr` (medium rule). These are special `iopart.cls` commands.

(v) Numbers in columns should be aligned on the decimal point; to help do this a control sequence `\lineup` has been defined in `iopart.cls` which sets `\0` equal to a space the size of a digit, `\m` to be a space the width of a minus sign, and `\-` to be a left overlapping minus sign. `\-` is for use in text mode while the other two commands may be used in maths or text. (`\lineup` should only be used within a table environment after the caption so that `\-` has its normal meaning elsewhere.) See table 5 for an example of a table where `\lineup` has been used.

11.2. Simplified coding and extra features for tables

The basic coding format can be simplified using extra commands provided in the `iopart` class file. The commands up to and including the start of the tabular environment can be replaced by

```
\Table{\label{label}Table caption}
```

and this also activates the definitions within `\lineup`. The final three lines can also be reduced to `\endTable` or `\endtab`. Similarly for a table which does not fit on the page when indented `\fulltable{\label{label}caption}` ... `\endfulltable` can be used. LaTeX optional positional parameters can, if desired, be added after `\Table{\label{label}caption}` and `\fulltable{\label{label}caption}`.

`\centre{#1}{#2}` can be used to centre a heading `#2` over `#1` columns and `\crule{#1}` puts a rule across `#1` columns. A negative space `\ns` is usually useful to reduce the space between a centred heading and a centred rule. `\ns` should occur immediately after the `\\` of the row containing the centred heading (see code for table 6).

Table 6. A table with headings spanning two columns and containing notes. To improve the visual effect a negative skip (\ns) has been put in between the lines of the headings. Commands set-up by \lineup are used to aid alignment in columns. \lineup is defined within the \Table definition.

Nucleus	Thickness ($mg\,cm^{-2}$)	Composition	Separation energies	
			γ, n (MeV)	γ, 2n (MeV)
^{181}Ta	19.3 ± 0.1[a]	Natural	7.6	14.2
^{208}Pb	3.8 ± 0.8[b]	99% enriched	7.4	14.1
^{209}Bi	2.86 ± 0.01[b]	Natural	7.5	14.4

[a] Self-supporting.
[b] Deposited over Al backing.

A small space can be inserted between rows of the table with \ms and a half line space with \bs (both must follow a \\ but should not have a \\ following them).

Units should not normally be given within the body of a table but given in brackets following the column heading; however, they can be included in the caption for long column headings or complicated units. Where possible tables should not be broken over pages. If a table has related notes these should appear directly below the table rather than at the bottom of the page. Notes can be designated with footnote symbols (preferable when there are only a few notes) or superscripted small roman letters. The notes are set to the same width as the table and in normal tables follow after \end{tabular}, each note preceded by \item[]. For a full width table \noindent should precede the note rather than \item[]. To simplify the coding \tabnotes can, if desired, replace \end{tabular} and \endtabnotes replaces \end{indented}\end{table}.

If all the tables are grouped at the end of a document the command \Tables is used to start a new page and set a heading 'Tables and table captions'. If the tables follow an appendix then add the command \noappendix to revert to normal style numbering.

12. Figures and figure captions

Figures (with their captions) can be incorporated into the text at the appropriate position or grouped together at the end of the article. If the figures are at the end of the article and follow an appendix then in iopart.cls you can add the command \noappendix to revert to normal style numbering. We remind you that you must seek permission to reuse any previously-published figures, and acknowledge their use correctly—see section 4.2.

12.1. Inclusion of graphics files

Using the graphicx package graphics files can be included within figure and center environments at an appropriate point within the text using code such as:

```
\includegraphics{file.eps}
```

The `graphicx` package supports various optional arguments to control the appearance of the figure. Other similar packages can also be used (e.g. `graphics`, `epsf`). Whatever package you use, you must include it explicitly after the `\documentclass` declaration using (say) `\usepackage{graphicx}`.

For more detail about graphics inclusion see the documentation of the `graphicx` package, refer to one of the books on LaTeX, e.g. Goosens M, Rahtz S and Mittelbach F 1997 *The* LaTeX *Graphics Companion* (Reading, MA: Addison-Wesley), or download some of the excellent free documentation available via the Comprehensive TeX Archive Network (CTAN) `http://www.ctan.org`—in particular see Reckdahl K 2006 *Using Imported Graphics in* LaTeX *and* pdfLaTeX `http://www.ctan.org/tex-archive/info/epslatex`.

IOP Publishing's graphics guidelines provide further information on preparing `.eps` files.

We prefer you to use `.eps` files for your graphics, but we realise that converting other formats of graphics to `.eps` format can be troublesome. If you use PDF or bitmap-format graphics such as JPG or PNG that need to be included using the pdfTeX package, this is OK, but please bear in mind that the PDF you submit should use PDF standard 1.4 or lower (use `\pdfminorversion=4` at the start of the file).

The main LaTeX file must read in graphics files and subsidiary LaTeX files from the current directory, *not* from a subdirectory. Your submission files are stored on our systems in a single location and we will not be able to process your TeX file automatically if it relies on organization of the files into subdirectories.

12.2. Captions

Below each figure should be a brief caption describing it and, if necessary, interpreting the various lines and symbols on the figure. As much lettering as possible should be removed from the figure itself and included in the caption. If a figure has parts, these should be labelled (a), (b), (c), etc and all parts should be described within a single caption. Table 7 gives the definitions for describing symbols and lines often used within figure captions (more symbols are available when using the optional packages loading the AMS extension fonts).

12.3. Supplementary Data

All of our journals encourage authors to submit supplementary data attachments to enhance the online versions of published research articles. Supplementary data enhancements typically consist of video clips, animations or data files, tables of extra information or extra figures. They can add to the reader's understanding and present results in attractive ways that go beyond what can be presented in the PDF version of the article. See our supplementary data guidelines for further details.

Table 7. Control sequences to describe lines and symbols in figure captions.

Control sequence	Output	Control sequence	Output
`\dotted`	·····	`\opencircle`	○
`\dashed`	- - - -	`\opentriangle`	△
`\broken`	– – –	`\opentriangledown`	▽
`\longbroken`	— — —	`\fullsquare`	■
`\chain`	— · —	`\opensquare`	□
`\dashddot`	— · · —	`\fullcircle`	●
`\full`	——	`\opendiamond`	♢

Software, in the form of input scripts for mathematical packages (such as Mathematica notebook files), or source code that can be interpreted or compiled (such as Python scripts or Fortran or C programs), or executable files, can sometimes be accepted as supplementary data, but the journal may ask you for assurances about the software and distribute them from the article web page only subject to a disclaimer. Contact the journal in the first instance if you want to submit software.

Appendix A. List of macros for formatting text, figures and tables

Table A1. Macros available for use in text in `iopart.cls`. Parameters in square brackets are optional.

Macro name	Purpose
`\title[#1]{#2}`	Title of article and short title (optional)
`\paper[#1]{#2}`	Title of paper and short title (optional)
`\letter{#1}`	Title of Letter to the Editor
`\ftc{#1}`	Title of Fast Track Communication
`\rapid[#1]{#2}`	Title of Rapid Communication and short title (optional)
`\comment[#1]{#2}`	Title of Comment and short title (optional)
`\topical[#1]{#2}`	Title of Topical Review and short title (optional)
`\review[#1]{#2}`	Title of review article and short title (optional)
`\note[#1]{#2}`	Title of Note and short title (optional)
`\prelim[#1]{#2}`	Title of Preliminary Communication & short title
`\author{#1}`	List of all authors
`\article[#1]{#2}{#3}`	Type and title of other articles and short title (optional)
`\address{#1}`	Address of author
`\ams{#1}`	Mathematics Classification Scheme
`\submitto{#1}`	'Submitted to' message
`\maketitle`	Creates title page
`\begin{abstract}`	Start of abstract
`\end{abstract}`	End of abstract
`\nosections`	Inserts space before text when no sections
`\section{#1}`	Section heading
`\subsection{#1}`	Subsection heading
`\subsubsection{#1}`	Subsubsection heading
`\appendix`	Start of appendixes
`\ack`	Acknowledgments heading
`\References`	Heading for reference list
`\begin{harvard}`	Start of alphabetic reference list
`\end{harvard}`	End of alphabetic reference list
`\begin{thebibliography}{#1}`	Start of numeric reference list
`\end{thebibliography}`	End of numeric reference list
`\etal`	*et al* for text and reference lists
`\nonum`	Unnumbered entry in numerical reference list

Table A2. Macros defined within `iopart.cls` for use with figures and tables.

Macro name	Purpose
`\Figures`	Heading for list of figure captions
`\Figure{#1}`	Figure caption
`\Tables`	Heading for tables and table captions
`\Table{#1}`	Table caption
`\fulltable{#1}`	Table caption for full width table
`\endTable`	End of table created with `\Table`
`\endfulltab`	End of table created with `\fulltable`
`\endtab`	End of table
`\br`	Bold rule for tables
`\mr`	Medium rule for tables
`\ns`	Small negative space for use in table
`\centre{#1}{#2}`	Centre heading over columns
`\crule{#1}`	Centre rule over columns
`\lineup`	Set macros for alignment in columns
`\m`	Space equal to width of minus sign
`\-`	Left overhanging minus sign
`\0`	Space equal to width of a digit

Table A3. Abbreviations in `iopart.cls` for journals handled by IOP Publishing.

Short form of journal title	Macro	Short form of journal title	Macro
2D Mater.	`\TDM`	J. Radiol. Prot.	`\JRP`
AJ	`\AJ`	J. Semicond.	`\JOS`
ApJ	`\APJ`	J. Stat. Mech.	`\JSTAT`
ApJL	`\APJL`	Laser Phys.	`\LP`
ApJS	`\APJS`	Laser Phys. Lett.	`\LPL`
Adv. Nat. Sci: Nanosci. Nanotechnol.	`\ANSN`	Metrologia	`\MET`
Appl. Phys. Express	`\APEX`	Mater. Res. Express	`\MRE`
Biofabrication	`\BF`	Meas. Sci. Technol.	`\MST`
Bioinspir. Biomim.	`\BB`	Methods Appl. Fluoresc.	`\MAF`
Biomed. Mater.	`\BMM`	Modelling Simul. Mater. Sci. Eng.	`\MSMSE`
Chin. J. Chem. Phys.	`\CJCP`	Nucl. Fusion	`\NF`
Chinese Phys. B	`\CPB`	New J. Phys.	`\NJP`
Chinese Phys. C	`\CPC`	Nonlinearity	`\NL`
Chinese Phys. Lett.	`\CPL`	Nanotechnology	`\NT`
Class. Quantum Grav.	`\CQG`	Phys. Biol.	`\PB`
Commun. Theor. Phys.	`\CTP`	Phys. Educ.	`\PED`
Comput. Sci. Disc.	`\CSD`	Phys.-Usp.	`\PHU`
Environ. Res. Lett.	`\ERL`	Physiol. Meas.	`\PM`
EPL	`\EPL`	Phys. Med. Biol.	`\PMB`
Eur. J. Phys.	`\EJP`	Phys. Scr.	`\PS`
Fluid Dyn. Res.	`\FDR`	Plasma Phys. Control. Fusion	`\PPCF`
Inverse Problems	`\IP`	Plasma Sci. Technol.	`\PST`
Izv. Math.	`\IZV`	Plasma Sources Sci. Technol.	`\PSST`
Jpn. J. Appl. Phys.	`\JJAP`	Quantum Electron.	`\QEL`
J. Breath Res.	`\JBR`	Rep. Prog. Phys.	`\RPP`
JCAP	`\JCAP`	Res. Astron. Astrophys.	`\RAA`
J. Geophys. Eng.	`\JGE`	Russ. Chem. Rev.	`\RCR`
JINST	`\JINST`	Russ. Math. Surv.	`\RMS`
J. Micromech. Microeng.	`\JMM`	Sb. Math.	`\MSB`
J. Neural Eng.	`\JNE`	Science Foundation in China	`\SFC`
J. Opt.	`\JOPT`	Sci. Technol. Adv. Mater.	`\STAM`
J. Phys. A: Math. Theor.	`\jpa`	Semicond. Sci. Technol.	`\SST`
J. Phys. B: At. Mol. Opt. Phys.	`\jpb`	Smart Mater. Struct.	`\SMS`
J. Phys: Condens. Matter	`\JPCM`	Supercond. Sci. Technol.	`\SUST`
J. Phys. D: Appl. Phys.	`\JPD`	Surf. Topogr.: Metrol. Prop.	`\STMP`
J. Phys. G: Nucl. Part. Phys.	`\jpg`	Transl. Mater. Res.	`\TMR`
IOP Conference Series journals			
J. Phys.: Conf. Ser.	`\JPCS`		
IOP Conf. Ser.: Earth Environ. Sci.	`\EES`		
IOP Conf. Ser.: Mater. Sci. Eng.	`\MSE`		

Table A4. Abbreviations for IOP Publishing journals that are no longer published.

Short form of journal title	Macro name	Years relevant
J. Phys. A: Math. Gen.	`\JPA`	1975–2006
J. Phys. B: At. Mol. Phys.	`\JPB`	1968–1987
J. Phys. C: Solid State Phys.	`\JPC`	1968–1988
J. Phys. E: Sci. Instrum.	`\JPE`	1968–1989
J. Phys. F: Met. Phys.	`\JPF`	1971–1988
J. Phys. G: Nucl. Phys.	`\JPG`	1975–1988
Pure Appl. Opt.	`\PAO`	1992–1998
Quantum Opt.	`\QO`	1989–1994
Quantum Semiclass. Opt.	`\QSO`	1995–1998
J. Opt. A: Pure Appl. Opt.	`\JOA`	1999–2009
J. Opt. B: Quantum Semiclass. Opt.	`\JOB`	1999–2005

Table A5. Abbreviations in `iopart.cls` for some common journals not handled by IOP Publishing.

Short form of journal	Macro	Short form of Journal	Macro
Acta Crystallogr.	`\AC`	J. Quant. Spectrosc. Radiat. Transfer	`\JQSRT`
Acta Metall.	`\AM`	Nuovo Cimento	`\NC`
Ann. Phys., Lpz	`\AP`	Nucl. Instrum. Methods	`\NIM`
Ann. Phys., NY	`\APNY`	Nucl. Phys.	`\NP`
Ann. Phys., Paris	`\APP`	Phys. Fluids	`\PF`
Can. J. Phys.	`\CJP`	Phys. Lett.	`\PL`
Gen. Rel. Grav.	`\GRG`	Phys. Rev.	`\PR`
J. Appl. Phys.	`\JAP`	Phys. Rev. Lett.	`\PRL`
J. Chem. Phys.	`\JCP`	Proc. R. Soc.	`\PRS`
J. High Energy Phys.	`\JHEP`	Phys. Status Solidi	`\PSS`
J. Magn. Magn. Mater.	`\JMMM`	Phil. Trans. R. Soc.	`\PTRS`
J. Math. Phys.	`\JMP`	Rev. Mod. Phys.	`\RMP`
J. Opt. Soc. Am.	`\JOSA`	Rev. Sci. Instrum.	`\RSI`
J. Physique	`\JP`	Solid State Commun.	`\SSC`
J. Phys. Chem.	`\JPhCh`	Sov. Phys.–JETP	`\SPJ`
J. Phys. Soc. Jpn.	`\JPSJ`	Z. Phys.	`\ZP`

Appendix B. Including author names using Chinese, Japanese and Korean characters in submissions to IOP Publishing journals

Authors in all IOP Publishing journals have the option to include names in Chinese, Japanese or Korean (CJK) characters in addition to the English name. The names will be displayed in the print issue and the online PDF, abstract and table of contents, in parentheses after the English name.

It is the decision of the individual authors whether or not to include a CJK version of their names; for a single article it is not necessary for all authors to include a CJK name if only one author wishes to do so. It is the responsibility of the authors to check the accuracy and formatting of the names in the final proofs that they receive prior to publication.

To include names in CJK characters, authors should use the `cjk.sty` package, available from `http://www.ctan.org/tex-archive/language/chinese/CJK/`. Users should be aware that this is a very large and complicated package which relies on a large number of fonts. We recommend using a TeX package that includes this package and all of the fonts by default, so that manual configuration is not required (e.g. the TeXLive distribution, which is available on all platforms (Macintosh, Windows and Linux)).

The documentation for the `cjk.sty` package gives information on how CJK characters can be included in TeX files. Most authors will find it convenient to include the characters in one of the standard encodings such as UTF-8, GB or JIS, if they have access to a text editor that supports such encodings.

Example TeX coding might be:

```
\documentclass[12pt]{iopart}
\usepackage{CJK}
.
.
.
\begin{document}
\begin{CJK*}{GBK}{ }

\title[]{Title of article}
\author{Author Name (CJK characters)}
\address{Department, University, City, Country}
.
.
.
\end{CJK*}
```

To avoid potential problems in handling the CJK characters in submissions, authors should always include a PDF of the full version of their papers (including all figure files, tables, references etc) with the CJK characters in it.

Appendix C. Examples

The entries in the reference list below provide examples of the formatting of various types of references, of varying complexity, including journal articles, articles in proceedings or collections, books (individual, multivolume, or in a series), theses, and unpublished references. The database entries used to generate these examples can be found in the file `iopart-num.bib`. Refs. [1, 2, 3, 4, 5, 6, 7, 8, 9] are based upon example entries from the IOP guidelines.

References

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[5] Harrison M 1999 Dipheomorphism-invariant manifolds (*Preprint* `hep-th/9909196`)
[6] Dorman L I 1975 *Variations of Galactic Cosmic Rays* (Moscow: Moscow State University Press) p 103
[7] Caplar R and Kulisic P 1973 *Proc. Int. Conf. on Nuclear Physics (Munich)* vol 1 (Amsterdam: North-Holland/American Elsevier) p 517
[8] Morse M 1996 Supersonic beam sources *Atomic Molecular and Optical Physics* (*Experimental Methods in the Physical Sciences* vol 29) ed Dunning F B and Hulet R (San Diego: Academic)
[9] Fulco C E, Liverman C T and Sox H C (eds) 2000 *Gulf War and Health* vol 1 *Depleted Uranium, Pyridostigmine Bromide, Sarin, and Vaccines* (Washington, DC: The National Academies Press)