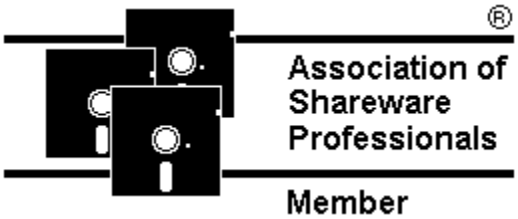
Periodic Table
Version 2.02
User's Guide



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About Periodic Table

Thank you for choosing Periodic Table 2.02. You have chosen the best Electronic Periodic Table on the market. Version was a significant upgrade to Periodic Table 1.53. Version 2.02 is a maintenance release, which fixes known bugs, adds a feature to have Periodic Table come up with the Table window maximized, and 3-D dialogs as seen in Microsoft Excel 4.0. However, we are always looking for new features to add. If you have any ideas please let us know, we'll be happy to hear from you. Note that beginning with this version, source code is no longer available. Also note that Periodic Table 2.02 requires Windows 3.1. Lastly, a printed version of this manual is available for a small fee.

Again, thank you for choosing Periodic Table, and thank you for supporting shareware by registering this application. You can find an order form at the end of this document, in the help file, and in the file ORDER.TXT that was included on the Install Disk or in the .ZIP file.

If you received Periodic Table as a ZIP files, you should find the following files included. If you received Periodic Table on diskette, you should check to see that the files listed as being on Disk 1 or Disk 2 are on the proper diskettes.

PT202A.ZIP	ZIP file for the **Periodic Table Installation Disk**
INSTALL.EXE	The installation program
INSTALL.BIN	An installation support file
INSTALL.BMP	An installation support file
INSTALL.INF	The installation script
PTOE.EX$	Periodic Table program
PTOE.HL$	Periodic Table help file
ELEM0000.DA$	Nuclide database
ELEM0001.DA$	Daughter nuclide database
ELEM0000.KE$	Nuclide database key file
ELEM0001.KE$	Daughter nuclide database key file
ELEM.DBD	Nuclide/Daughter database description file
FILE_ID.DIZ	BBS description file
PT202B.ZIP	ZIP file for the **Periodic Table Document Disk**
PTOE.WR$	This Manual
ORDER.TXT	ASCII order form
CTL3D.DL$	Microsoft 3-D control library
VENDOR.DOC	A file of information for disk vendors
SYSOP.DOC	A file of information of BBS sysops
FILE_ID.DIZ	BBS Description file
UNPACK.EXE	A program to unpack individual files from the install disk
DUNPACK.EXE	A DOS program to unpack individual files from the install disk

Files that end in a '$' are packed. To copy them individually to your hard disk, you will need to use the UNPACK.EXE program provided on the Install disk and in your installation directory. You may also find a README.TXT file if there are any late breaking changes that did not make it into the manual. **Be sure to read this file first if it is there**.

Installing Periodic Table

If you received Periodic Table as a ZIP file, and you are using 360kb disks, please unzip PT202A.ZIP and PT202B.ZIP to separate diskettes and label them with the names shown above. If you are unziping the files to a disk format greater than 360kb, then you can unzip both files to the same diskette.

If you received Periodic Table on diskette, and your disk format is greater than 360kb, then you will receive only one diskette with all files on it. The installation will proceed normally without asking you to change diskettes.

Insert your Installation Disk in drive A: Then from the File/Run command of either Program Manager or File Manager type:

```
a:\install
```

Click **OK** and follow the on screen prompts. (The installation will work from drive B: also)

About This Document

This document was formatted on a Windows 3.1 system for an HP LaserJet III printer. It uses the TrueType™ fonts Arial, Symbol and Courier. If you have a different printer, you may need to repaginate this manual. Helv or Helvetica may be substitued for Arial if you wish.

This manual contains many illustrations. If you want it to print faster or do not want the illustrations, you may delete them without affecting the overall content of the manual.

Entering Your License Number

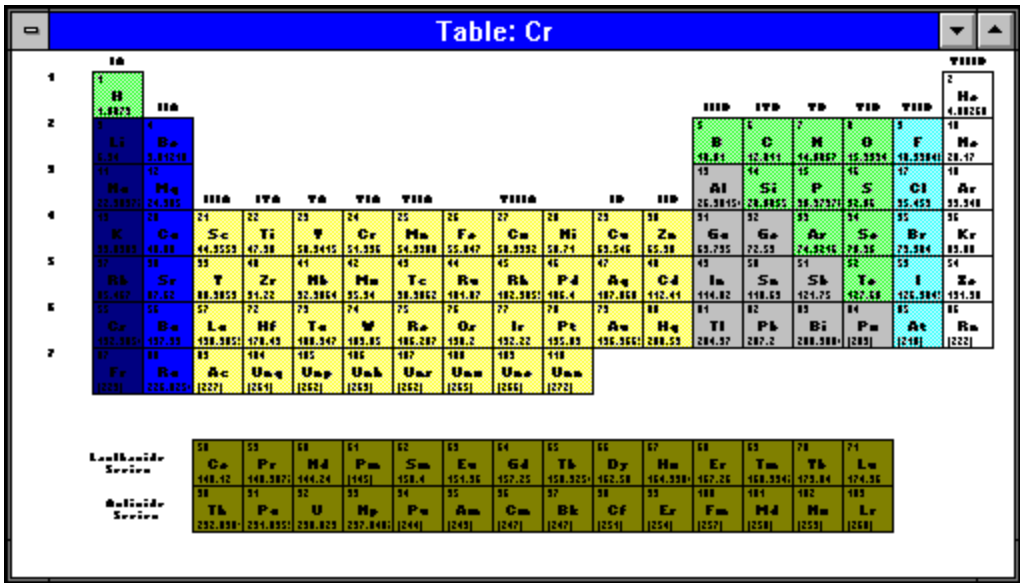
Once you have registered the program and received you license number you will be able to remove the reminder dialog. Start Periodic Table as usual. When the reminder dialog starts press the Enter Lic # button. You should now have a new dialog requesting your name and your license number. Enter the license number as shown on your paid invoice. Enter your name or any other identifying description in the other field. Press the OK button. If you entered the license number correctly you will be thanked for registering and the next time you start Periodic Table it will NOT display the reminder dialog. If you enter it incorrectly then exit Periodic Table, restart it and try again.

Application Overview

Periodic Table is designed for use by individuals ranging from students of chemistry, chemistry hobbyists, industry professionals, and academic researchers as well as instructors of chemistry. Periodic Table provides comprehensive and detailed element information ranging from atomic number to thermal conductivity. It also provides information on over 890 isotopes of the 110 elements, including abundance, half-life and decay mode. Periodic Table supports the use of the Windows clipboard and DDE to aid in using the information in presentations, school homework, and technical documents. Periodic Table also allows you to print much of its data.

The topics that follow give a brief overview of Periodic Table. For more detail on individual commands see the **Reference Section**.

Using the Table Window



The Table Window displays the Periodic Table of the elements. This chart is colored according to the Mode you have selected in the Option Menu. Each element box contains three items. At the top is the atomic number of the element. Next is the symbol for the element. Along the bottom of the box is displayed a line of data. The type of data shown is determined by the option chosen from the Option/Detail Menu.

You can get more detail about a particular element shown on the Periodic Table by using the following procedure:

1. Move the mouse pointer over the element you want to know about.
2. Double-click the left mouse button.

or

1. Use the arrow keys to highlight the element you want information on.
2. Press the Enter key.

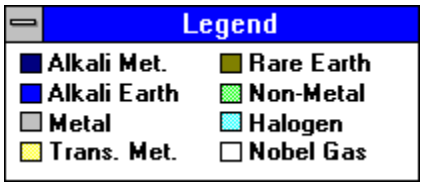
A window will open giving you more information about the element. It will show such things as who discovered the element, where it comes from and what it is used for.

Using the Legend

The legend will be displayed whenever the Legend option is turned on. The default is to display a legend.

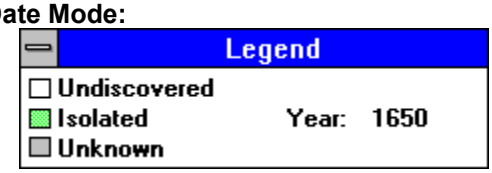
The information displayed in the Legend depends on the Mode selected from the Options menu.

Group Mode:



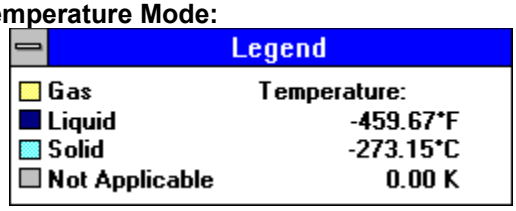
The Legend shows the colors used to represent each group of the Periodic Table.

Date Mode:



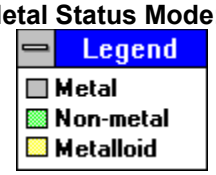
The Legend shows the year and the colors used to represent the discovery status of the elements on that date. The date is changed by using the horizontal scroll bar.

Temperature Mode:



The Legend shows the temperature in Kelvin, Celsius, and Fahrenheit and the colors used to represent the physical state of the elements at that temperature. The temperature is changed by using the horizontal scroll bar.

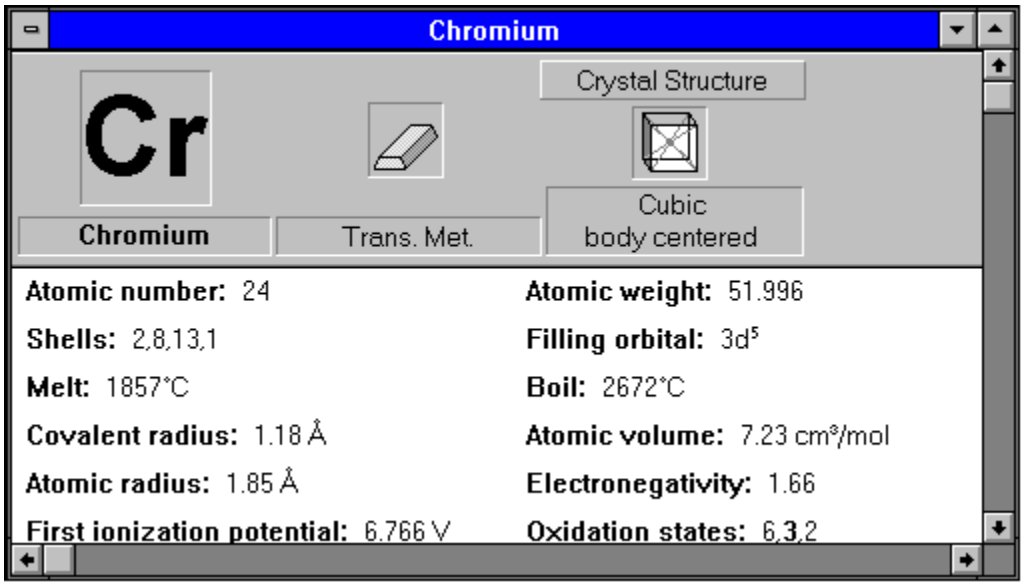
Metal Status Mode:



The Legend shows the three general types of elements; Metal, Non-metal and Metalloid along with the color used to represent it.

To change a group's color, double-click on the color box to the left of the group name. The Set Color dialog box will open. You can then change the color. To remove the Legend you can choose Close from its system menu, double click its system menu icon, press Alt+F4 when the Legend's caption bar is highlighted or uncheck Legend from the Options Menu. To turn the Legend back on check Legend on the Options Menu.

Using the Data Window



This window is opened by double-clicking the left mouse button while the mouse pointer is positioned over an element in the Table window, or by pressing Enter after highlighting an element on the Table window with the cursor keys.

The top of the window shows the element's symbol and name. The icon in the center shows a representation of the element. For example, the element gold (Au) has an icon showing a gold bar. Under the icon is a label that changes depending on the type of element displayed. Choose that topic in the Help menu to get general information about that type of element. The icon under the label Crystal Structure is a representation of the element's crystal structure. Under the icon is the name of the type of structure.

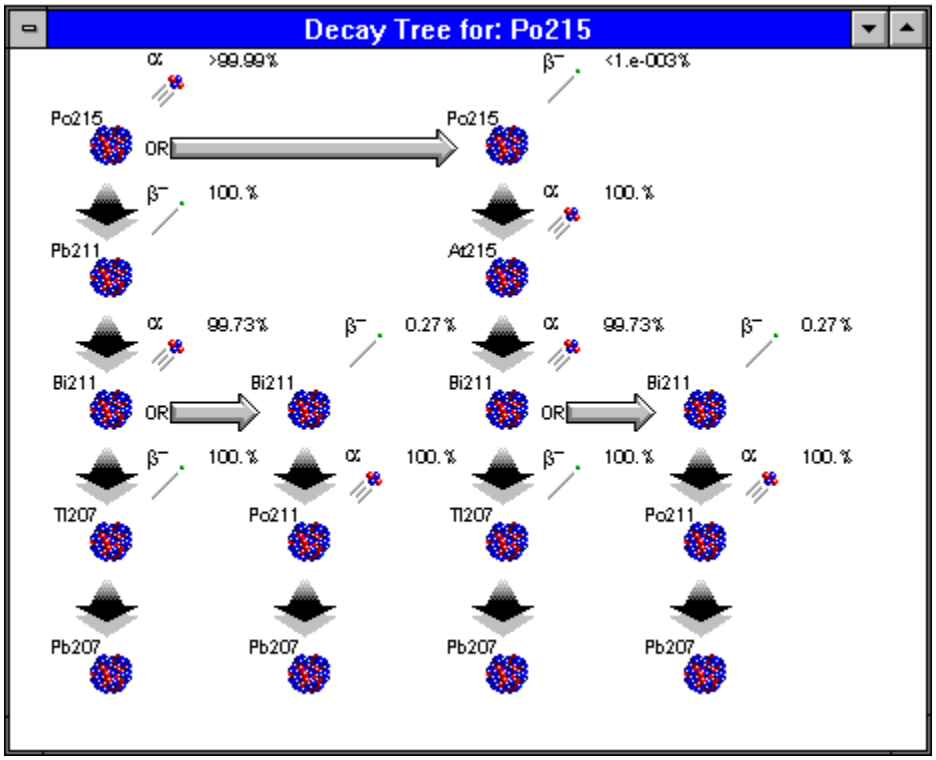
The window shows additional information on the element, depending on which mode you have chosen. If Data is selected (the default), it shows the atomic number, atomic weight, electron shell configuration, subshell being filled, electronegativity, density, atomic radius, covalent radius, atomic volume, specific heat, density, first, second and third ionization potentials, heat of vaporization, heat of fusion, electrical conductivity, and thermal conductivity.

If What/When/Where is selected, the discoverer of the element, discoverer's country, when it was discovered, where the element is usually obtained, and some of its uses, are displayed.

If Isotopes is selected, then all isotopes (nuclides) in the database for this element are shown. Also displayed for each nuclide are abundance, mass, spin, half-life, and decay modes.

You can change the data being shown by pressing Ctrl+D, Ctrl+W, or Ctrl+I for Data, What/When/Where, and Isotopes, respectively. You can also change the data shown by clicking the right mouse button and selecting an item from the menu displayed. The information displayed may be copied to the clipboard by pressing Ctrl+Ins. You can change the element displayed by pressing Ctrl+, Ctrl+↓, Ctrl+←, or Ctrl+→.

Using the Decay Tree Window



This window is opened by selecting an isotope from the Radioactive Decay Menu on the Data window.

This window will display a tree showing the radioactive decay of the isotope selected. The selected isotope is displayed in the upper left corner of the window. Its mode of decay is shown to its right slightly higher than the isotope itself. The daughter nuclide resulting from the decay is shown below its parent; following the dark black arrow.

If a nuclide has more than one possible mode of decay the second mode is shown to the right. Follow the arrow to the right. The percentage of decays in that mode will be shown to the right of the decay mode.

The symbols used in the decay tree are:

α	alpha decay
β^-	beta decay
$\beta^-\beta^-$	double beta decay
β^+	positron decay
ε	electron capture
IT	isomeric transition
SF	spontaneous fission

The Decay Tree window will beep when it has completed generating the decay tree. Some trees will take several seconds to build.

Use the scroll bars or the arrow keys to view all parts of the tree if it is too large to fit in the window.

Exiting

You may exit Periodic Table in one of the following ways:

1. Choose Close from the system menu.
2. Press the Alt+F4 key combination.
3. Double-click on the system menu icon.
4. Choose Exit from the File Menu.
5. Press F3.

Using DDE

Periodic Table supports DDE to allow data to be transfered from Periodic to another program such as a word processor or a spreadsheet. Below is a list of all DDE topics and items supported by Periodic Table. To find out how to establish the DDE link see the documentation for the application that will be requesting information from Periodic Table.

Topics are in bold face. The items for that topic are listed indented below the topic name. All items are currently supported in text only.

System

Topics -	lists all topics
SysItems -	lists system items supported
Formats -	lists supported formats
Help -	sends a help text about DDE

Units

SysItems -	lists system items supported in this topic
AtomicRadius-	returns units used for atomic radius
Density -	returns units used for density
Ionization -	returns units used for ionization potential
SpecificHeat -	returns units used for specific heat
CovalentRadius	returns units used for covalent radius
AtomicVolume	returns units used for atomic volume
HeatVapor -	returns units used for heat of vaporization
HeatFusion -	returns units used for heat of fusion
Melt -	returns units used for melting point
Boil -	returns units used for boiling point
ElectricalCond -	returns units used for electrical conductivity
ThermalCond -	returns units used for thermal conductivity

element name (i.e. Hydrogen; each element name is a topic)

SysItems -	lists system items supported in this topic
Symbol -	element symbol
Number -	atomic number
Weight -	atomic weight
Electrons -	electrons in each shell
Shells -	filling subshell
Group -	periodic group
MetalStatus -	metal/nonmetal/metaloid
Crystal -	crystal structure
Isotopes -	all isotope data for element

Discoverer - who first isolated the element
DiscoveryLocation - where isolated
DiscoveryDate - when isolated
Description - element description
Sources - where element can be found
Uses - uses for element
Melt - melting point of element
Boil - boiling point of element
Electronegativity - element's electronegativity
NameOrigin - origin of the element's name
Radius - atomic radius of element
Density - density of element
Oxidation - oxidation states (most stable in parens)
Ionization - first ionization potential of element
Ionization2 - second ionization potential of element
Ionization3 - third ionization potential of element
SpecificHeat - specific heat of element
CovalentRadius - covalent radius of element
Volume - atomic volume of element
HeatVaporization - heat of vaporization of element
HeatFusion - heat of fusion of element
ElectricalCond - electrical conductivity of element
ThermalCond - thermal conductivity of element

Reference Section

This section gives detail on all the commands available in Periodic Table.

Table Window Commands

Below are listed the commands available in the Table Window.

File Menu Commands
- Data Window
- Close
- Print
- Quiz
- List by Property
- Bond Character
- Exit

Option Menu Commands
- Mode
- Detail
- Legend
- Maximize at Startup
- PrintColor
- Font/Colors
- Save

Window Menu Commands
- Cascade
- Tile
- Arrange Icons
- Close All

File Menu Commands

The following are the commands available on the file menu.

Data Window - F4
This command will open a Data Window for the element that is currently blinking in the Table window.

Close
This command will close the Table window. You will not be able to open new data windows until you open the Table window again.

Print - Ctrl+P
This command will print the Periodic Table using the current settings.

Quiz Menu
Choosing this item will open another menu with the following commands.

Element Name - Ctrl+N
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct symbol.

Element Symbol - Ctrl+S
This command will open a quiz dialog box. This quiz will display an element symbol and you must choose the correct name.

Element Group - Ctrl+G
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct periodic group to which it belongs.

Atomic Number - Ctrl+A
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct atomic number.

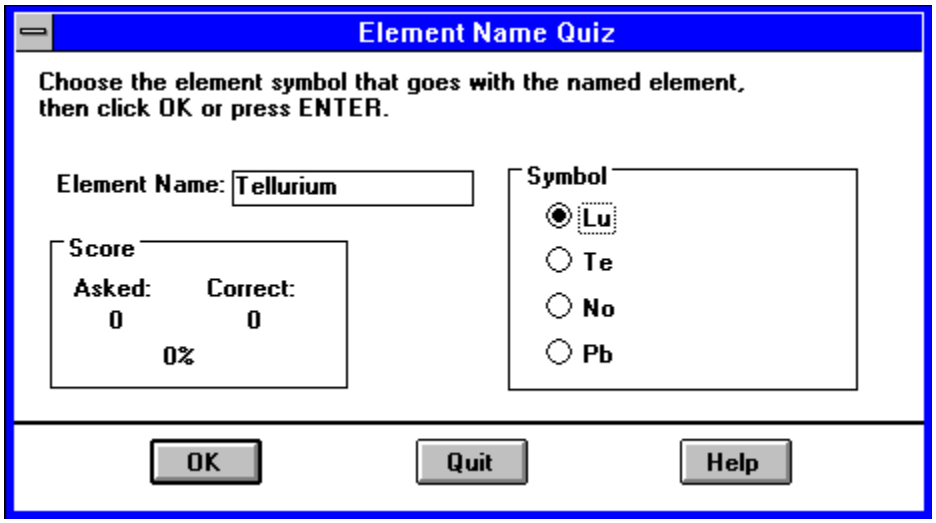
List by Property - Ctrl+L
This command will display a dialog box that will list the elements by various properties, in ascending or descending order. You may print the list.

Bond Character - Ctrl+B
This command will display a dialog box that will allow you to compare chemical bond characteristics of two elements.

Exit - F3
This command will exit Periodic Table.

Element Name Quiz Command

All quizzes have the same format. Below is a sample of the Element Name Quiz. It looks similar to, and works the same as all the other quizzes.



This dialog box has several controls.

Element Name:

This box shows the name of an element from the periodic table. This is the name that you must match with its proper symbol.

Symbol:
This group of radio buttons allows you to choose the symbol that belongs to the name shown at the left.

Score:
This box displays the number of questions asked and the number of your responses that were correct. Below this is displayed the percentage of correct responses.

Once you have selected the proper symbol to go with the name press the OK button or press the Enter key. When you wish to quit press the QUIT button. Pressing the HELP button displays this help topic.

Element Symbol Quiz Command

This dialog box has several controls.

Element Symbol:
This box shows the symbol for an element from the periodic table. This is the symbol that you must match with its proper name.

Name:
This group of radio buttons allows you to choose the name that corresponds to the symbol shown at the left.

Score:
This box displays the number of questions asked and the number of your responses that were correct. Below this is displayed the percentage of correct responses.

Once you have selected the proper name to go with the symbol press the OK button or press the Enter key. When you wish to quit press the QUIT button. Pressing the HELP button displays this help topic.

Element Group Quiz Command

This dialog box has several controls.

Element Name:
This box shows the name of an element from the periodic table. This is the name that you must match with periodic group to which it belongs.

Symbol:
This group of radio buttons allows you to choose the periodic group that the element named at the left belongs to.

Score:
This box displays the number of questions asked and the number of your responses that were correct. Below this is displayed the percentage of correct responses.

Once you have selected the proper periodic group to go with the name press the OK button or press the Enter key. When you wish to quit press the QUIT button. Pressing the HELP button displays this help topic.

Atomic Number Quiz Command

This dialog box has several controls.

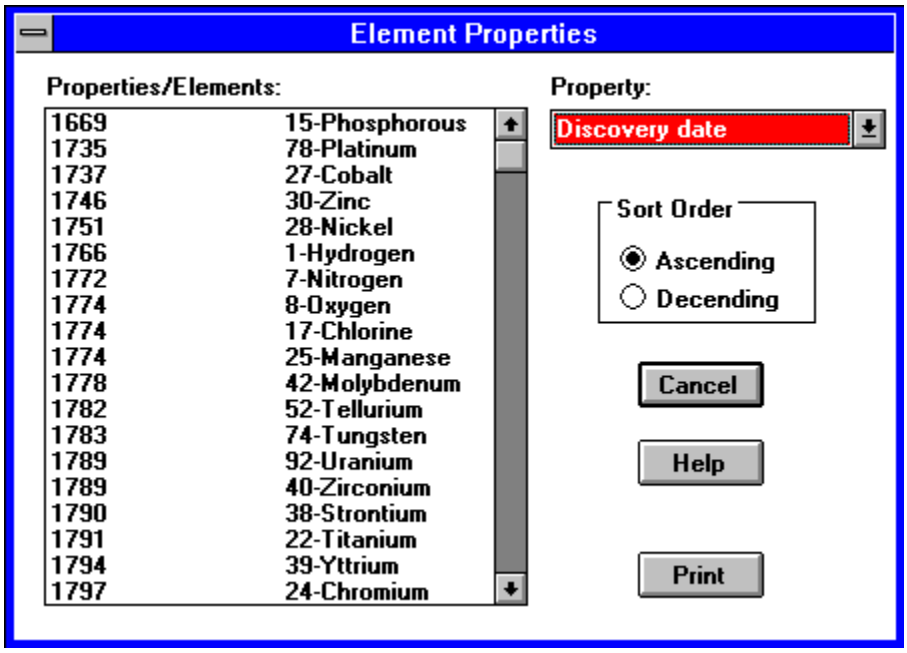
Element Name:
This box shows the name of an element from the periodic table. This is the name that you must match with its proper atomic number.

Atomic Number:
This group of radio buttons allows you to choose the atomic number that belongs to the name shown at the left.

Score:
This box displays the number of questions asked and the number of your responses that were correct. Below this is displayed the percentage of correct responses.

Once you have selected the proper atomic number to go with the name press the OK button or press the Enter key. When you wish to quit press the QUIT button. Pressing the HELP button displays this help topic.

List by Properties Command



This dialog box has several controls.

Property/Element:
This list box shows the element property followed by the element name. The element names are prefixed by their atomic number. The property being listed is the one named in the Property combo box. The list box is sorted in either ascending or descending order depending on which option is checked in the Sort Order box. Elements which have no value or which have no known value for the selected property are listed last.

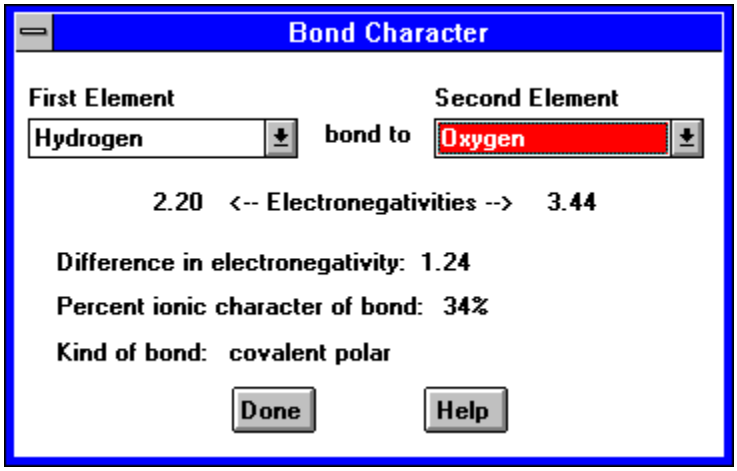
Property:
This combo box lists all the properties that can be listed. When you choose a different property the Property/Element list box is immediately updated.

Sort Order:
This box has two radio buttons. One for ascending order and one for descending order. You may choose only one. When you change the selection the Property/Element list box is immediately updated.

You may print the list in its displayed order by pressing the PRINT button.

When you wish to quit press the CANCEL button. Pressing the HELP button displays help topic about the dialog.

Bond Characteristics Dialog



This dialog box allows the user to determine the single bond characteristic between any two elements.

Choose any element in the dropdown listbox for the first and second element. When you choose an element, its electronegativity is displayed below its name. The difference between the two is shown along with the ionic character of the bond. Also shown is the type of bond: covalent non-polar, covalent polar and ionic.

When you have finished press the Done button. The Help button will bring up a help topic about the dialog box.

Option Menu Commands

The following are the commands available on the option menu.

Mode Command
Selecting this command will display another menu that will allow you to choose the type of information to be displayed in the Legend window and the way the elements are colored. You may choose Groups, Date, Temperature, or Metal Status. The current mode will be shown with a check mark beside its name.

Detail Command
Selecting this command will display another menu that will allow you to choose the type of information to be displayed at the bottom of each element in the table. You may choose any displayed item. The current detail choice will be shown with a check mark beside its name.

Legend
This command indicates whether the Legend window will be used. If the menu item is checked the Legend will display, otherwise it will not.

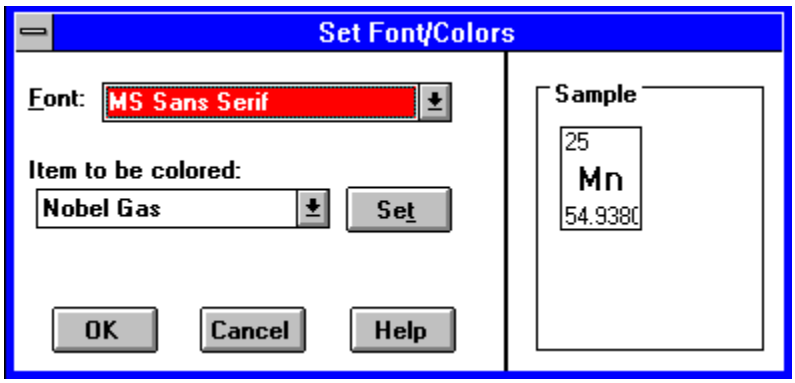
Maximize at Startup
This command indicates whether the Table window will start up maximized each time Periodic Table is started. If the menu item is checked the Table window will start maximized, otherwise it will not.

Print Colors
This command indicates whether or not you want the colors printed when you print the periodic table. If you do not have a color printer the Windows printer driver will attempt to create a dithered pattern to simulate the color. If you do not want dithered colors printed uncheck this item.

Font/Colors
Opens a dialog box showing the current font and color. Make any changes you desire, (the changes will be previewed in the sample window) then choose the OK button. The CANCEL button will exit the dialog without making any changes.

Save
Selecting this command will cause Periodic Table to save its current options to the PTOE.INI file. These options will be used the next time you start Periodic Table.

Font/Colors Command



This dialog box has the following controls.

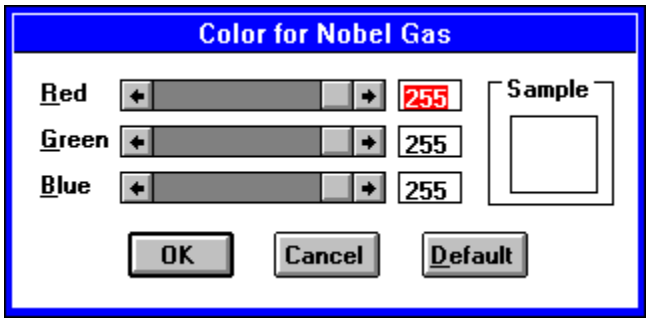
Font:
This combo box shows the current font that is used to draw the Periodic Table. By clicking on the drop down button you will see all available fonts. Highlight the one you want to use and press TAB or click on the drop down button again. You can also use the up/down arrow keys to change the font selection. Any change made here will be previewed in the sample window.

Item to be Colored:
This group of controls allows you to change the colors of the element groups.

The first control is a combo box that contains all the element groups. When you have selected the group you want to change, press the SET button. This will bring up the Set Color dialog box. This will allow you to change the color of the group. Any change you make here will be reflected in the preview window.

Once the above options have been selected press the OK button to see them. You may press the CANCEL button to abort changing any of the current options.

Set Color Dialog Box



The Set Color dialog box allows you to change the color of any of the groups of elements. To use the dialog you can use the scroll bars or you can enter a value in the edit control at the end of the scroll bar.

There is a scroll bar for each of the primary colors, Red, Green, and Blue. As you move the slider of a scroll bar to the right, the value will increase up to the maximum of 255. You can set each scroll bar independently of the others.

At the right of the scroll bars is a sample of the color based on the current scroll bar settings.

When you have a color you like press the OK button to exit the dialog. The Periodic Table will be re-drawn using your new color.

If you don't want to change the color press CANCEL. Any changes made to the current color will be ignored, and you will exit the dialog.

The DEFAULT button will change the color back to the program defined color. You can then start making changes again or exit the dialog.

Window Menu Commands

Cascade - Shift+F5
Arranges open windows so that the title bar of each window is visible.

Tile - Shift+F4
Arranges open windows side by side so that all of them are visible.

Arrange Icons
Arranges into rows all window icons into rows.

Close All
Closes all open windows but does not exit the application.

Data Window Commands

Below are listed the commands available to the Data window.

File Menu Commands
- Close
- Print
- Quiz
- List by Property
- Bond Character
- Exit

Edit Menu Commands
- Copy Current
- Copy Data
- Copy What/When/Where
- Copy Isotopes

Mode Menu Commands
- Data
- What/When/Where
- Isotopes
- Radioactive Decay
- Save Mode

Period Menu Commands
- Up
- Down

Group Menu Commands
- Left
- Right

Window Menu Commands
- Cascade
- Tile
- Arrange Icons
- Close All

File Menu Commands

The following are the commands available on the file menu.

Close
This command will close the Data window

Print - Ctrl+P
This command will print all the data for the displayed element, regardless of what type of data is shown in the window.

Quiz Menu

Element Name - Ctrl+N
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct symbol.

Element Symbol - Ctrl+S
This command will open a quiz dialog box. This quiz will display an element symbol and you must choose the correct name.

Element Group - Ctrl+G
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct periodic group to which it belongs.

Atomic Number - Ctrl+A
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct atomic number.

List by Property - Ctrl+L
This command will display a dialog box that will list the elements by various properties, in ascending or descending order. You may print the list.

Bond Character - Ctrl+B
This command will display a dialog box that will allow you to compare chemical bond characteristics of two elements.

Exit - F3
This command will exit Periodic Table.

Edit Menu Commands

Copy Current - Ctrl+Ins
This command will copy the data displayed in the current Data window to the clipboard.

Copy Data - Alt+D
This command will copy the portion of information about the current element referred to as 'data' to the clipboard, whether or not it is currently displayed. This information consists of the atomic number, atomic weight, electronegativity, etc.

Copy What/When/Where - Alt+W
This command will copy the portion of information about the current element referred to as 'what/when/where' to the clipboard, whether or not it is currently displayed. This data consists of who discovered the element, where it was discovered, what its uses are, etc.

Copy Isotopes - Alt+I
This command will copy the portion of information about the current element referred to as 'isotopes' to the clipboard, whether or not it is currently displayed. This data consists of all the isotopes in the database for this element along with their spin, half-life, decay mode, abundance, etc.

Mode Menu Commands

Data - Ctrl+D
This command will display the portion of information about the current element referred to as 'data'. This

information consists of the atomic number, atomic weight, electronegativity, density, atomic radius, covalent radius, atomic volume, specific heat, density, first ionization potential, heat of vaporization, heat of fusion, and discovery date.

What/When/Where - Ctrl+W
This command will display the portion of information about the current element referred to as 'what/when/where'. This data consists of who discovered the element, where it was discovered, what its uses are, etc.

Isotopes - Ctrl+I
This command will display the portion of information about the current element referred to as 'isotopes'. This data consists of all the isotopes in the database for this element along with their spin, half-life, decay mode, abundance, and mass.

Radioactive Decay
This command will only appear on the menu if there are isotopes of the element that are unstable. Choosing this command will open a Decay Tree Window for the nuclide (isotope) selected.

Save Mode
This command will save the currently displayed mode to the PTOE.INI file. Then each time a new Data window is opened the type of data set by the mode will be the one initially shown.

Period Menu Commands

Up - Ctrl+UpArrow
This command will change Data window to display data for the element from the Periodic Table that is above the currently shown element. In essence, move to the period above the current element.

Down - Ctrl+DownArrow
This command will change Data window to display data for the element from the Periodic Table that is below the currently shown element. In essence, move to the period below the current element.

Group Menu Commands

Left - Ctrl+LeftArrow
This command will change Data window to display data for the element from the Periodic Table that is to the left of the currently shown element. In essence, move to the group following the current element.

Right - Ctrl+RightArrow
This command will change Data window to display data for the element from the Periodic Table that is to the right of the currently shown element. In essence, move to the group preceding the current element.

Decay Tree Window Commands

Below are listed the commands available to the Decay Tree window.

File Menu Commands
- Close
- Print
- Quiz
- List by Property
- Bond Character
- Exit

Info Commands
- Nuclides
- Radioactive Decay
- Subatomic Particles

Window Menu Commands
- Cascade
- Tile
- Arrange Icons
- Close All

File Menu Commands

The following are the commands available on the file menu.

Close
This command will close the Decay window

Print - Ctrl+P
This command will print the displayed decay tree.

Quiz Menu

Element Name - Ctrl+N
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct symbol.

Element Symbol - Ctrl+S
This command will open a quiz dialog box. This quiz will display an element symbol and you must choose the correct name.

Element Group - Ctrl+G
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct periodic group to which it belongs.

Atomic Number - Ctrl+A
This command will open a quiz dialog box. This quiz will display an element name and you must choose the correct atomic number.

List by Property - Ctrl+L

This command will display a dialog box that will list the elements by various properties, in ascending or descending order. You may print the list.

Bond Character - Ctrl+B
This command will display a dialog box that will allow you to compare chemical bond characteristics of two elements.

Exit - F3
This command will exit Periodic Table.

Info Menu Commands

The following are the commands available on the info menu.

Nuclides
This command will open a help window to provide background information about nuclides.

Radioactive Decay
This command will open a help window to provide background information about radioactive decay.

Subatomic Particles
This command will open a help window to provide background information about subatomic particles.

Periodic Law

It became evident early in the science of chemistry that certain elements could be grouped together by the similarities of their physical properties. For example, lithium, sodium and potassium have similar properties as do fluorine, chlorine, bromine and iodine.

In 1829, the German chemist Döbereiner, became the first to propose a relationship between atomic weights and the properties of elements. He was able to show that strontium has properties about midway between calcium and barium.

The English chemist Newlands, in 1865, saw a correlation between the atomic weights and the properties of the elements. Mendeleev in Russia and Lothar Meyer in Germany, in 1870, working independently and unaware of Newlands, outlined this relationship in detail.

This led to a statement that the properties of the elements are periodic functions of their atomic weights. The below series illustrates the point:

Li	Be	B	C	N	O	F	Ne
6.94	9.01	10.81	12.01	14.01	16.00	18.00	20.18
Na	Mg	Al	Si	P	S	Cl	Ar
22.00	24.31	26.98	28.09	30.97	32.06	35.45	39.95

In each row elements differ quite a bit in properties. There is, however, an interesting graduation of properties as atomic weight increases. Note that elements in a vertical column have similar properties. For example, lithium is similar to sodium.

Moseley showed that atomic number rather than atomic weights are the determining factor of chemical properties. If you check the Periodic Table you can see that argon (At. Wt. 39.948) precedes potassium (At. Wt. 39.098). There are other reversals in the table as well. This is due to the abundance of heavier isotopes of some elements. This affects the atomic weight, which is an average.

The formal statement of the Periodic Law is: **The properties of the elements are periodic functions of their atomic numbers.**

Electron Shells

As atomic number increases so too does the number of electrons in a neutral atom of the element. The valence electrons are largely responsible for its chemical behavior. If elements having the same number of valence electrons are grouped together the elements in each group or family will have similar chemical properties.

The **first short** period contains only two elements. These elements fill the K shell. It ends with helium which contains a full K shell consisting of two electrons.

The **second short period** contains eight elements beginning with lithium and ending with neon. Neon has a complete L shell of eight electrons.

The **third short period** contains eight elements beginning with sodium. It ends with argon, which contains eight electrons in the M shell.

The **fourth period** contains eighteen elements beginning with potassium. It includes a series of elements from scandium through copper. These elements are known as **transition elements**.

They are building the M shell from eight to eighteen electrons. Before this series begins though, two electrons enter the outermost N shell. After the transition series the N shell then builds up to eight electrons ending with krypton.

The **fifth period** is just like the fourth period in which the O shell takes two electrons then the N shell builds to eighteen electrons before the O shell continues out to eight electrons ending with xenon.

The **sixth period** contains 32 elements. It begins with the P shell taking two electrons. It too has a transition series beginning with lanthanum and ending with gold, in which the O shell fills to eighteen electrons.

Note however that this series is split after lanthanum with a series of fourteen elements. In these elements the N shell (third from the outside) is filling from eighteen to 32 electrons. These are referred to as the **inner transition series**, **lanthanum series** or the **rare earth** elements. It begins with cerium and ends with lutetium.

Following lutetium the transition series from hafnium to gold completes by building the O shell to eighteen electrons. The outer P shell then continues to build to eight electrons ending with radon.

The **seventh period** is incomplete. The first two elements, francium and radium fill the Q shell with two electrons. Then the P and O shells fill in the same way as the sixth period. This produces the **actinide series**.

Electron Subshells

Each of the electron shells, designated by the letters K, L, M, N, O, P, and Q or the numbers 1, 2, 3, 4, 5, 6, and 7, are subdivided further into **subshells**.

The first principal shell, the K shell, has one subshell designated as the 1*s* shell. The second principal shell has two subshells designated as 2*s* and 2*p*. The third shell has three subshells designated 3*s*, 3*p*, and 3*d*. The fourth shell has four subshells, 4*s*, 4*p*, 4*d*, and 4*f*.

The subshells are further divided into **orbitals**, each can contain a maximum of two electrons. Therefore an *s* subshell, which is made up of one orbital, can contain a maximum of two electrons. A *p* subshell has three orbitals and can contain six electrons. A *d* subshell has five orbitals and can contain ten electrons. An *f* subshell has seven orbitals and can contain fourteen electrons.

On the average, an *s* electron will approach the nucleus more closely than a *p* of the same principal shell, a *p* electron more closely than a *d* electron, and a *d* electron more closely than an *f* electron.

The notation used in describing electron structures consists of a principal shell number in front of the subshell letter and a superscript to designate the number of electrons in that particular subshell. For example $3d^4$ indicates that there are four electrons in subshell *d* of the M shell.

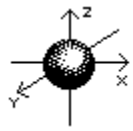
Electron Orbital Shapes

The orbitals occupied by electrons in different subshells differ from each other with regard to their size, shape, and orientation in space. The larger the number of the principal shell, the greater the volume of the corresponding orbital.

For example, a 2*s* electron has an orbital of greater volume than a 1*s* electron. However, the orbitals of the higher principal shells overlap those of lower shells. This means that the outer electrons penetrate the regions occupied by inner electrons.

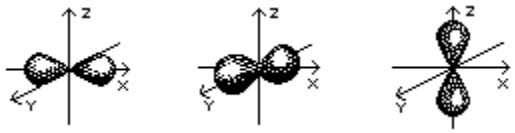
The shape of an *s* electron orbital is spherical while that of a *p* electron orbital is dumbbell shaped.

The number of possible orientations of atomic orbitals in space depends to an extent on the shape of the orbital. An *s* orbital still presents the same appearance to an outside observer since its shape is that of a sphere. Therefore an *s* orbital is said to be spherically symmetrical and without directional characteristics.



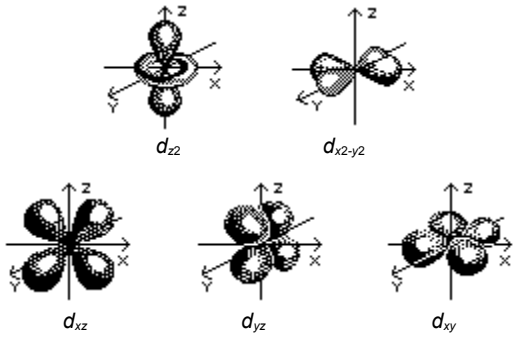
s orbitals

It is a bit more complex with *p* orbitals which occur in sets of three. It is not possible to determine the direction of any one orbital in a given set. However, the axes along which the three *p* orbitals lie are mutually at right angles to each other. The three *p* orbitals are designated as p_x, p_y and p_z to emphasize their directional nature.



p_x p_y p_z

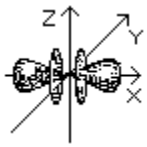
The five *d* orbitals consist of lobe-shaped regions arranged in space as shown below. The drawings are oriented so that the lobes of the orbitals designated d_{z2} and d_{x2-y2} lie along the axes and the lobes of the d_{xz}, d_{yz}, and d_{xy} lie in between the axes.



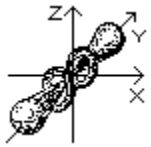
d_{z2} d_{x2-y2}

d_{xz} d_{yz} d_{xy}

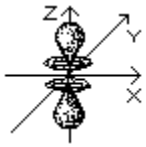
The seven *f* orbital are not understood well enough to have good agreement on their shape and orientation in space. Below is shown one way of representing the *f* orbitals.



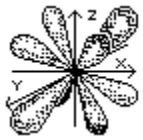
$f_x3_{-3/5xr}2$



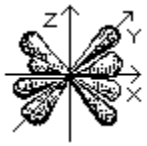
$f_y3_{-3/5yr}2$



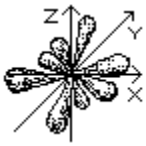
$f_z3_{-3/5zr}2$



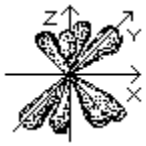
f_{xyz}



$f_{x(z2-y2)}$



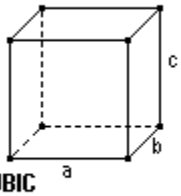
$f_{y(x2-z2)}$



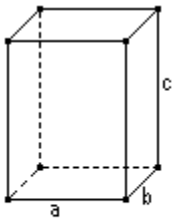
$f_{z(x2-y2)}$

Crystal Structures

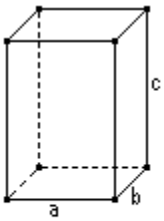
The elements have been classified by their crystaline structure when solidified. Below are diagrams depicting the six basic crystal configurations.



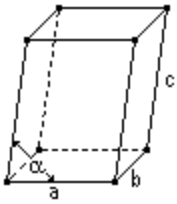
CUBIC
a = b = c
All right angles



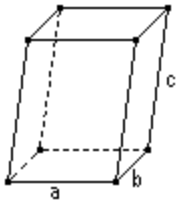
TETRAGONAL
a = b ≠ c
All right angles



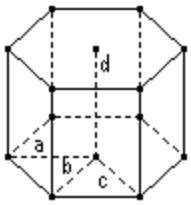
ORTHORHOMBIC
a ≠ b ≠ c
All right angles



MONOCLINIC
a ≠ b ≠ c
α ≠ 90°



RHOMBOHEDRAL
a ≠ b ≠ c
No right angles



HEXAGONAL
a = b = c ≠ d
d at 90° to plane a,b,c

Rare Earth Elements

These **elements** got their name from the fact that chemists first isolated them in their oxide forms. These oxides somewhat resemble calcium, magnesium and aluminum oxides, sometimes called common earths.

The rare earths all have three **valence electrons**. Because of this they all have similar properties.

Transition Metal Elements

This group of metals are distinguished from other metals not by their physical properties, but by their electronic structure. The transition metals have their **valence electrons** in more than one shell. Regular, or representative, metals have their valence electrons in only one shell.

The transition metals include the **elements** of the groups IIIA through IIB in each of the long **periods** of the periodic table.

The transition metals are noted for their variability in **oxidation state**. This is attributed to the presence of valence electrons in more than one shell. Whereas, the representative metals have only one or two oxidation states, since they have valence electrons in only one shell.

Thus, manganese has two electrons in its outside shell and five electrons in the next shell down, and exhibits oxidation states of +1, +2, +3, +4, +5, +6, and +7.

They are also characterized by the fact that well into the series, going from left to right, the properties of succeeding metals do not differ greatly from preceding ones. This is attributed to the fact that, generally, succeeding elements differ in electronic structure by one electron in the next to the outer valence shell rather than the outer shell.

In contrast, those of succeeding representative metals in a period differ extensively, since they differ by one electron in the outer valence shell.

Alkali Metal Elements

Alkali metal is a term that refers to six **elements**: lithium, sodium, potassium, rubidium, cesium, and francium. These elements make up group IA of the periodic table of elements. They all form singly-charged positive ions, and are extremely reactive. They react violently with water, forming **hydroxides** and releasing hydrogen gas and heat. Cesium and francium are the most reactive and lithium is the least.

Alkali Earth Metal Elements

Alkali earth metal is a term that refers to six **elements**: beryllium, magnesium, calcium, strontium, barium, and radium. These elements make up group IIA of the periodic table of elements. They all exhibit a single oxidation state, +2. They are all light and very reactive. Barium and radium are the most reactive and beryllium is the least.

The term "earth" was formerly used by chemists to denote slightly soluble metal oxides. The oxides of barium, strontium, and calcium resemble alumina (Al_2O_3), a typical "earth", but form alkaline mixtures with water. For this reason barium, strontium, and calcium were called alkaline earth metals. This name has now been extended to include all of the elements of group IIA.

Metal Elements

Chemists use a test called an electrolysis test to determine if an **element** is metallic or non-metallic. This test consists of dissolving the element in acid and running an electric current through the solution. If the element is metallic, the atoms of the element will show a positive charge. That is they will seek the negative pole.

Formally it is stated as **"those elements which, when in solution in a pure state, carry a positive charge and seek the negative pole in an electric cell".**

Properties of metals that are familiar to everyone include:

1. They are good conductors of heat and electricity
2. They are usually opaque to light
3. They have metallic luster

The difference in chemical properties between metals and non-metals lies mainly in the fact that atoms of non-metals will readily fill their **valence** shells by sharing **electrons** with or transferring electrons to other atoms.

For example, chlorine, a typical non-metal, will readily enter into combination with another atom by adding one electron to an outer shell of seven: gaining an electron from or sharing a pair with the other atom. Whereas, an atom of say sodium, a typical metal, enters into combination by the loss of its single valence electron.

Metallic characteristics of the elements decrease and non-metallic characteristics increase with the increase of valence electrons. Also metallic characteristics increase with the number of **electron shells**. Therefore there is no sharp dividing line between the metals and the non-metals.

There are elements that are definitely on the border between metal and non-metal. These elements will show hybrid behavior. They are sometimes called **metalloids**. Many of them have been called semiconductors. This group of elements include boron, silicon, germanium, arsenic, antimony, tellurium, and astatine.

Physical properties of metals generally include:

1. They are good conductors of heat and electricity.
2. They are malleable and **ductile** in their solid state.
3. They show metallic luster.
4. They are opaque.
5. They have high **density**.
6. They are solids (except mercury)
7. They have crystal structure in which each atom is surrounded by eight to twelve near neighbors

Chemical properties of metals generally are:

1. They have one to four **valence** electrons.
2. They have low ionization potentials; they readily lose electrons.
3. They are good **reducing** agents.
4. They have **hydroxides** which are bases or **amphoteric**.
5. They are **electropositive**.

Of the 110 elements now known, only 17 show primarily non-metallic characteristics, 8 others are metalloids, and 85 may be classed as metals.

Halogen Elements

The **halogens** are the elements astatine, fluorine, chlorine, bromine, and iodine. They are non-metals, and make up part of the seventh group in the periodic table.

Halogen means salt forming. The halogens all have a strong unpleasant odor and will burn flesh. They do not dissolve well in water. Because they are so active, none of them are found free in nature.

The five elements are strongly electronegative. They are oxidizing agents, with fluorine being the strongest and astatine being the weakest. They react with most metals and many non-metals.

As the atomic structure of the halogens becomes more complex with increasing atomic weight there is a gradation in physical properties. For example: Fluorine is a pale green gas of low **density**. Chlorine is a greenish-yellow gas 1.892 times as dense as fluorine. Bromine is a deep reddish-brown liquid which is three times as dense as water. Iodine is a grayish-black crystalline solid with a metallic appearance. And astatine is a solid with properties which indicate that it is somewhat metallic in character.

Noble Gas Elements

Noble gas refers to any **element** of the group of six elements in group 8 of the periodic table. They are argon, helium, krypton, neon, radon, and xenon. Unlike most elements, the noble gases are **monoatomic**. The atoms have stable configurations of **electrons**. Therefore under normal conditions they do not form compounds with other elements.

They were generally called inert gases until about 1962 when xenon tetrafluoride, XeF_4, was produced in the laboratory. **This was the first report of a stable compound of a noble gas with another single element.**

Non-Metal Elements

Non-metals are basically defined as elements that are not **metals**.

Their physical properties generally include:

1. They are poor conductors.
2. They are brittle, not **ductile** in their solid state.
3. They show no metallic luster.
4. They may be transparent or translucent.
5. They have low **density**.
6. They are gases, liquids, or solids.
7. They form molecules which consists of atoms **covalently** bonded; the noble gases are **monoatomic**.

Their chemical properties are generally:

1. They usually have four to eight **valence electrons**.
2. They have high electron affinities. (except the noble gases)
3. They are good **oxidizing** agents. (except the noble gases)

4. They have **hydroxides** which are acidic. (except the noble gases)
5. They are **electronegative**.

Radioactive Decay

Radioactive decay is the breakdown of an atomic nucleus. To understand how nuclei break apart we must first examine how nuclei are put together. To begin with let's study carbon-12. Its mass is defined to be 12.0000 and all other nuclei are measured against this standard.

Carbon-12 has twelve particles in its **nucleus**: 6 **protons** and 6 **neutrons**. It would then seem that each proton and neutron should have a mass of 1.0000. However, measurements of the mass of the proton curving in a magnetic field of known strength show the mass of the proton as 1.00734.

A neutron, since it is uncharged, does not curve in a magnetic field. But, its mass has been measured in other ways. Chadwick, in 1934, measured the energy it took to break apart a hydrogen-2 nucleus. The mass of the hydrogen-2 nucleus was known. He then subtracted the mass of the proton and added the energy needed to break the nucleus up (remember that mass and energy are related by Einstein's famous equation). The mass left over was the mass of the neutron, which is 1.00867, or about .0014% heavier than the proton.

Adding up 6 protons and 6 neutrons leaves us 0.096 heavier than the mass of carbon-12. In 1927, Aston, found that all nuclei had masses slightly less that the total mass of the protons and neutrons. Aston called this the mass defect.

The fraction of the total mass that this mass defect consists of is called the packing fraction. It is calculated for carbon-12 as follows. the defect of 0.096 is divided by 12 which gives 0.008. Scientists then multiply this number by 10,000 to avoid working with small numbers, which makes the packing fraction 80 for carbon-12.

In general, the packing fractions of all nuclei increase up to iron-56 which has a packing fraction of 94.0. At that point the packing fractions begin to decrease until by the time you get to uranium-238 you have a packing fraction of only 79.4. We will see a significance to iron-56 later in our discussion.

Where did the mass making up the mass defect go? It turned into energy, of course. When 6 protons and 6 neutrons are formed into a carbon-12 nucleus a small fraction of their mass is turned into energy and is dissipated into space. A process that dissipates energy has a tendency to occur. This means that protons and neutrons have a tendency to form nuclei.

To break up an atomic nucleus into its individual protons and neutrons requires energy to be supplied that is exactly equal to the amount of energy dissipated when the nucleus formed. Except upper extreme conditions this will not happen. Once a nucleus has formed it will retain the same identity. (Perhaps you are wondering why the nucleus holds together so well when there are so many positive charges packed so tightly together? It would seem that the nucleus should fly apart since a like charges repel each other. To see why this does not happen, see Interactions.)

But in order for a nucleus to change its identity it only has to gain or loose a proton or neutron to change into a different nucleus. In general, if such an event takes place and results in a higher packing fraction there will be a further dissipation of energy and therefore a certain tendency for the change to take place. From this you would expect that nuclei with lower mass numbers would change into nuclei with higher mass numbers and nuclei with high mass number to do the opposite with both processes converging on iron-56. With its maximum packing fraction, it would require an energy input to become larger or smaller. (This is one reason that massive stars explode into a supernova when they try to fuse iron in their cores. It requires an energy input which cools the star and begins its collapse.)

Due to certain factors light nuclei are prevented from sliding toward iron-56 on their own. But for

massive nuclei, (nuclei more massive than bismuth-209) the tendency is realized. They do tend to emit particles forming nuclei with higher packing fractions and dissipating energy.

The greater the dissipation of energy from one nucleus to another the more likely the change, the faster that change takes place, and the shorter the **half-life** of the original nucleus. For example, for thorium-232, uranium-235, and uranium-238 the change dissipates so little energy that their half-lives are very long.

Natural radioactivity involving nuclei with mass numbers from 232 to 238 changes them into nuclei with mass numbers from 206 to 208. The process increases their packing fractions, dissipating energy.

Helium-4 is a very stable nucleus. So stable that is has virtually no tendency to add either a proton or a neutron. Among nuclei of higher mass numbers, the nuclei that can be thought of as units of helium-4 are particularly stable. Carbon-12 (6 protons, 6 neutrons, 3 helium-4 units) and oxygen-16 (8 protons, 8 neutrons, 4 helium units) hold together tightly. They both have lower packing fractions than their neighboring nuclei.

As nuclei get more massive this effect seems to diminish. However, neon-20 (5 helium-4 units) magnesium-24(6), silicon-28(7), sulfur-32(8), and calcium-40(10) are particularly stable, and they are all the most common **isotopes** of their elements.

Beyond calcium-40 the helium-4 unit loses its stabilizing effect. It seems that as more protons are added it requires more than an equal number of neutrons to keep the nucleus stable. So that by the time you reach iron-56 you have a nucleus of 26 protons and 30 neutrons. Tin-118 has 50 protons and 68 neutrons. Gold-197 has 79 protons and 118 neutrons. Finally to bismuth-209, the heaviest stable nucleus, has 83 protons and 126 neutrons for a neutron/proton ratio of 1.52.

Past bismuth-209 no excess of neutrons will stabilize a nucleus. When a massive nucleus is so massive it is unstable, it has a tendency to lose particles in order to become less massive and therefore more stable. A good way to do this is to emit a helium-4 nucleus. These helium-4 nuclei are called alpha particles, and the process is called **alpha decay**.

Nuclei less massive than bismuth-209 usually do not emit alpha particles. Neodymium-144 is the lightest nucleus that does, but only very slowly. Lighter nuclei usually emit beta particles. A beta particle is emitted when a neutron is converted to a proton. The charge must be conserved, so since a neutron has no charge but a proton is positively charged there must be a negative charge to balance the reaction. The negative charge comes from the beta particle which is actually an **electron**. Therefore, beta emission involves a neutron changing to a proton and an electron. (It is actually more complicated than that, for a more detailed description see **Beta Decay**).

Alpha Decay

Past bismuth-209 no excess of **neutrons** will stabilize a **nucleus**. When a massive nucleus is so massive it is unstable, it has a tendency to lose particles in order to become less massive and therefore more stable. A good way to do this is to emit a helium-4 nucleus. It is light and holds together tightly, therefore it is easy to expel as a unit. This helium-4 unit is also called an alpha particle. Therefore, uranium-238, thorium-232, radium-226 and many other heavy nuclei emit alpha particles.

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Beta Decay

Beta decay occurs when a **nucleus** has too many **neutrons** for it to remain stable or nearly stable. In order to reset the imbalance the nucleus must convert one of its neutrons into a **proton**. Beta decay achieves this. The neutron emits a beta particle, which is a negatively charged **electron**, the neutron then gains a positive charge and becomes a proton.

For example, aluminum-28, with 13 protons and 15 neutrons has too many neutrons to be stable. So one of its neutrons emits a beta particle and becomes a proton. This converts the nucleus into silicon-28 with 14 protons and 14 neutrons, which is quite stable.

When a nucleus emits an alpha particle the resultant nucleus is slightly less massive than the mass of the original nucleus and the alpha particle added together. This difference in mass is accounted for by the kinetic energy of the alpha particle. This is not quite the situation for beta decay.

When a nucleus emits a beta particle the resultant nucleus should equal the mass of the original nucleus minus the mass of the beta particle minus the kinetic energy of the beta particle. Usually this is not the case. Normally the beta particle is moving more slowly than the mass loss indicates. This would appear to violate the law of conservation of energy.

For many years after beta emission was discovered the cause of the missing energy was unknown. Then in 1930, Pauli came up with a theory to explain the difference. He suggested that a second particle was emitted. In order to conserve charge the new particle must be electrically neutral, which would make detecting it much more difficult. (Remember that beta decay involves a neutron changing into a proton and emitting an electron therefore conserving charge. If another particle is emitted it must be neutral.)

The small amount of energy carried off by this new particle is just enough to account for its speed. Therefore, the particle must have almost no mass. In 1934, Fermi worked out in detail the properties of the particle and called it the **neutrino**.

Positron Decay

Positron decay (sometimes called positive beta decay) occurs when a nucleus has too few neutrons for it to remain stable or nearly stable. In order to reset the imbalance the nucleus must convert one of its protons into a neutron. Positron decay achieves this. The proton emits a **positron**, which is a positively charged electron, the proton then looses its positive charge and becomes a neutron.

For example, aluminum-26, with 13 protons and 13 neutrons has too few neutrons to be stable. So one of its protons emits a positron and becomes a neutron. This converts the nucleus into magnesium-26 with 12 protons and 14 neutrons, which is stable.

Positron emission does the opposite of electron (or beta) emission. In beta emission, the atomic number goes up by one by changing a neutron into a proton, positron emission causes the atomic number to go down by one by changing a proton into a neutron.

Free neutrons decay into less massive protons but free protons do not decay into more massive neutrons. How then can a proton in a nucleus decay into a neutron? In a nucleus where protons and neutrons are in close association it is the total mass that counts. In a nucleus with too few neutrons the total mass can go down if a proton changes into a neutron because the packing fraction increases. This allows the change to occur.

It is this that makes particular **isotopes** unstable. If the total mass of a nucleus is going to decrease if a proton changes into a neutron, or a neutron changes proton, then the change will happen. If an isotope has a mass that will increase if the change was made, the change will not take place and the isotope will remain stable. It just so happens that when there are either 43 or 61 protons in a nucleus, no matter how many neutrons are present, changing a proton to a neutron or vise versa will always decrease the mass. This is why there are no stable isotopes of technetium(43) or promethium(61).

There is one other way that a proton can change to a neutron. In this process the proton picks up an electron from outside the nucleus. This is called **electron capture**.

Electron Capture

Electron capture involves a proton in the nucleus picking up one of the electrons from outside the nucleus. This neutralizes the electric charge of the proton and converts it into a neutron. This electron almost always comes from the K **shell** since it is the shell nearest to the nucleus. Therefore the process is also called K capture. It was first observed in 1938 by Luis Alvarez. However, this process is much less likely to happen than positron emission.

Isomeric Transition

Sometimes when a decay occurs the resulting nucleus is that of a stable isotope but the decay has left the nucleus in an excited state. Many times this nucleus will then produce Isomeric Transition gamma rays. This dissipates the excess energy and the nucleus is now more stable. This does not result in a proton or neutron changing, therefore the nucleus has the same identity but a lower energy state.

Spontaneous Fission

Massive nuclei can undergo another kind of decay although for most it is rare. This decay is by spontaneous fission. This is where the nucleus breaks into two lighter nuclei without any energy added from outside. For example, uranium-238 undergoes 1 spontaneous fission for every 220 times its nuclei simply emit an **alpha** particle. Spontaneous fission was first detected by Georgii Flerov in 1941.

Even though it is rare, some radioactive nuclei show a much greater likelihood of undergoing spontaneous fission. The transuranic isotopes become more unstable not only in ordinary radioactivity but also in the probability of spontaneous fission. For example, where the spontaneous fission half-life of uranium-238 is about one trillion years, that of curium-242 is 7,200,000 years and californium-250 is only 15,000 years.

Isotopes

Isotope is a term proposed by Frederick Soddy, in 1913, to characterize a nucleus. It comes from Greek words meaning same place since all isotopes of an element fall into the same place on the periodic table. It refers to chemical elements that differ from one another only by the number of neutrons they posses. The term nuclide was proposed by Truman Kohman, in 1947, for a species of atom characterized by the number of neutrons and protons the atom contains. For example, oxygen-15, and oxygen-16 are isotopes of oxygen. They both have 8 protons but 7 and 8 neutrons respectively. Whereas, nitrogen-15, oxygen-16, and oxygen-17 are all nuclides. Nuclide is the more general term.

Isotopes were first discovered after the invention of the mass spectrograph, developed by Francis Aston. He was using the instrument to measure the relative mass of atoms of an element. First the atom is ionized by removing electrons. This makes the atom positively charged. The ion is then passed through

the mass spectrograph which has magnetic fields at right angles to each other to direct the ions to a photographic plate so that all ions with the same mass are brought to a focus at a fine line. Heavier ions would be deflected more that lighter ones.

For example, chlorine, whose atomic weight is 35.5, two lines are produced. One at about mass number 35 and another at about 37. No lines are found at 35.5. This confirms that chlorine consists of two isotopes one having mass 35 the other mass 37. When their natural abundance is taken into account they average out to 35.5.

Most elements in their natural state consists of two or more stable isotopes. (20 elements have only one stable isotope: for example, aluminum, cobalt, and gold.) Aston proposed a whole-number rule which says that all atomic masses are close to integers and that fractional atomic weights are due to the presence of two or more isotopes each having approximately integral values.

It is now believed that a neutral atom consists of N neutrons, Z protons and Z orbital electrons, and that A(mass) = N+Z. Isotopes are nuclides with the same Z but different N.

Half-Lives

Half-life is a term introduced by Ernest Rutherford in 1904. The half-life of a radioactive **nuclide** is the time it takes for half of the original nuclide to decay into daughter products. The following discussion will illustrate how this can be determined.

If a given quantity of a radioactive nuclide is observed, it will be seen that over time the number of decays declines. The reason is obvious. As the atoms decay there are fewer of the original atoms left to decay, therefore there are fewer decays to be observed.

The rate that the decays decline is a property of something called a first-order reaction. This means that each radioactive nuclide has a certain chance of decaying, and that chance does not change over time. If it has a one in two chance of decaying today then if it has not decayed in one hundred days it still has a one in two chance of decaying on the 101st day. This is the same as flipping a coin. You have a one in two chance of getting tails. Even if you have flipped 10 heads in a row you still have a one in two chance of getting tails on the 11th flip.

You can't tell when any particular atom will decay, but, if you have many atoms, you can calculate how many will decay in one day. It is just a matter of statistics. You can't tell which atom will decay but you will know how many will decay.

From this you can calculate how long it will take for half of the atoms to decay. In the case of first-order reactions, it always takes the same amount time for half of any quantity to decay. If you have a nuclide with a half-life of one year and you start with 100 grams, then in one year you will have 50 grams of the nuclide. In another year you will have 25 grams, after three 12.5 grams, after four 6.25 grams, etc.

To determine the half-life of a nuclide, scientists can, in many cases, count the number of alpha or beta particles given off by a nuclide over a period of time. From the way the count drops off they can calculate the time it would take half of the nuclide to decay.

Interactions

In classical physics the term force was used to describe electromagnetism and gravity. After the introduction of quantum mechanics, however, it became clear that these "forces" were actually interactions involving exchange particles. The exchange particles that mediate the interactions are

called "**gauge bosons**". Below we describe the four interactions.

Electromagnetic Interaction

Hideki Yukawa applied quantum mechanics to the electromagnetic interaction and found that, between charged particles, what was exchanged was **photons**. Between particles of the same charge, the exchange produced a repulsion, and between particles of opposite charge, it produced an attraction. It is an infinite range interaction and its effect declines slowly with distance. If you double the distance between particles the interaction's intensity decreases by one fourth.

Gravitational Interaction

The attraction between any two particles of mass is governed by the gravitational interaction. Any two particles with mass will rapidly exchange gravitons. Gravitons have not yet been detected because they are so weakly energetic, but scientists do not doubt that they exist. Since there is only one type of mass, the gravitational interaction produces only an attraction. It is an infinite range interaction and its effect declines slowly with distance. If you double the distance between particles the interaction's intensity decreases by one fourth.

Weak Interaction

This interaction governs the way in which neutrons give off electrons and **neutrinos**. It is a very short range interaction. Its range is 10^{-15} centimeters or about a thousandth of the width of an atomic nucleus. It is also very weak. It is only about a hundred-billionth a intense as the electromagnetic interaction. It plays almost no role in the nucleus but is important in individual particles. **Baryons**, **mesons** and **leptons** respond to this interaction. Events mediated by the weak interaction take place in about a millionth of a second. It is the only interaction that is not involved in a force of attraction. It merely mediates the conversion of certain particles into other particles, such as the decay of a **pion** into a **muon**, the decay of a muon into an electron, or the radioactive production of **beta** particles.

In 1967 a theory by Steven Weinberg, combined the electromagnetic and weak interactions. His combined interaction was called the electroweak interaction. It predicted four particles. One was massless, which was the photon. The other three had great mass and were called W particles, W^+ and W^- for the charged particles and Z^0 for the neutral one. In 1983 Carlo Rubbia announce discovery of the W^+ and W^- particles, and then in 1984, he announce the discovery of the Z^0 particle.

Strong Interaction

This interaction is what holds the protons and neutrons together in the nucleus. It is an extremely short range interaction. Its range is 10^{-18} centimeter or about a hundred-thousandth of the width of an atomic nucleus. If you double the distance between particles the interactions intensity drops to less than 1 percent of what it was.

In 1947 Cecil Powel found a particle called the pi meson, or pion. This is the exchange particle for the strong interaction. However, while it is a **boson** it is not a gauge boson. It is about 273 times as massive as the electron. It is the rapid exchange of pions in the nucleus of an atom that holds it together. Both baryons and mesons respond to this interaction. Leptons do not. Events mediated by the strong interaction take place in less than a trillionth of a second.

Something must be said here about the pion exchange particle. As was said it is not a gauge boson, it is instead a meson. Mesons are **hadrons** just as protons and neutrons are hadrons. Hadrons consists of **quarks**. The strong interaction is essentially an interaction between quarks. Hadrons experience the strong interaction secondarily because they are made up of quarks. Pions, which seem to be the

exchange particle for this secondary hadron interaction, are exchange particles only because they are made up of quarks. The fundamental strong interaction occurs between quarks. The exchange particle for the interaction between quarks is a gauge boson, called the **gluon**.

Subatomic Particles

As physicists probed deeper and deeper into the nucleus the began to find all sorts of strange forms of matter. Completely new particles were found and studied. The first of which were mesons, positrons, and muons. Later whole menageries of particles were found.

As more and more were found, scientists started to classify the particles by their quantum properties.

Fermions and Bosons

The highest level of classification was by **spin**. The spin quantum number of every particle is always an integer or half-integer. Particles with half-integer spins behave quite differently from particles that have integer spins. Particles with half-integer spins are called **fermions**, in honor of Enrico Fermi, who first described the behavior of this class or particle. The work on particles with integer spins was done by physicist Satyendra Nath Bose. These particles are named **bosons**. According to this scheme, pions and photons are bosons, while electrons and protons are fermions.

Hadrons

Hadrons are complex particles, in that, unlike leptons, they appear to have internal structure. They are made up of more fundamental particles called **quarks**. Most hadrons are unstable. Hadrons are subdivided into two groups: the baryons and the mesons. Hadrons are affected by the strong interaction.

Baryons

Baryons are fermions. They are generally heavier that mesons. They are made up of three quarks. Protons and neutrons are baryons. Baryons follow the law of conservation of baryon number. Baryons are given the baryon number of +1 and antibaryons have a baryon number of -1.

Mesons

Mesons are bosons. Because of quark **color** they are made up of two quarks, a quark and an antiquark. The pion is a meson. Mesons do not follow the law of conservation of baryon number and are given a baryon number of 0.

Leptons

Leptons are fermions. The appear to have no internal structure, and no size. In other words, they appear pointlike. There are three charged leptons known: the electron, the muon, and the tauon. They each have a corresponding neutrino: the electron neutrino, the muon neutrino, and the tauon neutrino. Each one has an anti-particle. Leptons are not affected by the strong interaction.

Gauge Bosons

The gauge bosons are obviously bosons. They are all exchange particles and are the mediating particles for the four **interactions**. There are four gauge bosons. The photon, which mediates the electromagnetic interaction. The W particles which mediate the weak interaction. The graviton which mediates the gravitational interaction. The fourth is the **gluon** which mediates the strong color interaction whose by-product is the strong interaction. They are all point-like particles, and therefore show no structure.

Neutrinos

In 1934, Fermi worked out in detail the properties of the neutrino. He believed it to be a particle with no mass, no electric charge, and virtually no tendency to interact with matter. It was a nothing particle. It might as well have been so except that it conserved several conservation laws that seemed to be violated during beta emission.

If a motionless neutron is allowed to decay into a proton and an electron, the electron will go flying off in some direction at great speed and therefore have a sizable momentum. The proton (formerly the neutron) will recoil in the opposite direction at a lesser speed but greater mass. The momentum of the electron (small mass × high velocity) should be equal to the momentum of the proton (high mass × low velocity). If they go off in opposite directions, one will have a momentum of +x, the other -x which will work out to a momentum change of 0. Therefore the law of conservation of momentum is conserved. Unfortunately this is not what happens. However, if a neutrino is also emitted, it can account for the missing momentum.

Consider also that the neutron has a **spin** of either +½ or -½. If only a proton and an electron were emitted there would be an imbalance in spin. A proton has a spin of +½ or -½ as does an electron. Therefore the total spin after the breakdown could be +1, -1, or 0. This means that the law of conservation of angular momentum would be broken. But, if the neutron also ejects a neutrino, which also has a spin of +½ or -½ then the total after the breakdown can add to +½ or -½ which is the spin of the original neutron, therefore conserving angular momentum.

There is another law of conservation that must also be conserved: the law of conservation of **lepton** number. The neutron and proton both have a lepton number of 0 (since they are **baryons**). The electron has a lepton number of +1 or -1, depending on the charge of the electron. (An electron has charge -1 and lepton number +1, a positron has a charge of +1 and a lepton number of -1.) The neutron, then, starts off with a baryon number of +1 and a lepton number of 0. When it breaks down, the proton has a baryon number of +1 and lepton number of 0 and the electron has a baryon number of 0 and a lepton number of +1, the baryon number is conserved but the lepton number is not. But, if a neutrino is formed with a lepton number of -1 and baryon number of 0, you have now conserved lepton number since you started with a neutron with baryon number +1 and lepton number 0 and formed three particles that total to baryon number +1 and lepton number of 0.

The -1 lepton number of the neutrino make it a mirror particle (or antineutrino) but this is fine, since an antineutrino conserves the laws of energy, charge, momentum, angular momentum, and lepton number just as well as a neutrino.

The detection of the neutrino took many years because it is exceedingly difficult to detect. It is calculated that a neutrino can pass through 3,500 light-years of solid lead before being absorbed. Of course, this is the average neutrino. Individual neutrinos might pass twice that far or only a millionth as far before being absorbed. This means that if you could produce a stream of trillions of trillions of neutrinos in a lab, a few just might happen to hit some particle and interact.

Just such a source is available: nuclear reactors. How are they produced? Uranium-235, which is used in many reactors, with its 92 protons requires 143 neutrons to keep its nucleus nearly stable. When the nucleus fissions into smaller nuclei, each requires fewer neutrons to be stable. This sets some neutrons free. Over a period of time these neutrons break down into protons and electrons producing antineutrinos as well. A typical reactor could produce a billion billion antineutrinos every second.

With a source of antineutrinos, the next thing to do was to decide what the antineutrino would do. Consider what would happen if an antineutrino hit a proton. If a antineutrino hits a proton, the proton will

emit a positron and change into a neutron. Note that this process conserve the law of baron number, proton +1 and neutron +1. It also conserves lepton number, antineutrino -1, positron -1. It conserves electric charge, proton +1, positron +1. The other conservation laws are also conserved.

The interaction can be detected because the positron that is emitted will strike an electron within a millionth of a second and they will mutually **annihilate** each other. The process produces two gamma rays of equal strength moving in opposite directions. The neutron produced in the antineutrino reaction could be absorbed by a cadmium atom which will produce gain energy and emit three or four photons of a fixed energy.

Finally, in 1956, Fredrick Reines and Clyde Cowan created a detector made up of a tank of water (Lots of protons in the water molecules.) with some cadmium chloride to absorb any neutrons produced. Then they added devices to detect the gamma rays, their directions, and their energies. Then they waited for the occasional antineutrino to interact with a proton, which they found. It was 26 years after Pauli suggested the existence of the neutrino.

Quarks

By the late 1950's there were hundreds of hadrons that had been discovered. It seemed that instead of simplifying matters, things were getting more complicated. Something was needed to put order to the growing hadron zoo.

There were two classes of hadrons. First was the baryons which were classed as **fermions** or hadrons with half-integer spins. The other was the **mesons** or hadrons with integer spins. But the classifying of hadrons into baryons and mesons was not enough.

In 1961, Murry Gell-Mann tried to do with hadrons what Mendeleev had done with elements by grouping the hadrons by their characteristics. This proved to be very successful as each of the hadrons began to fit into its own family. For example, the proton and neutron are members of a family of 8 hadrons. The other members of the family are the lambda, the three sigma, and the two xi particles.

In 1962, Gell-Mann used his theory to predict the existence of an undiscovered particle which he called the omega minus particle. It was to be the tenth member of a ten member family. By 1953 the particle had been found, giving further validity to the theory.

But just as when the periodic table was first presented, no one knew why Gell-Mann's theory was so successful. What made the hadrons fit so well into these groups? Many scientists believed that hadrons were elementary particles. But if they were why did it seem that there was an unlimited number of them?

Gell-Mann believed that there had to be an internal structure to hadrons that would allow them to be grouped. This was not an unbelievable idea, since leptons acted as though they were point-like, and hadrons did not. So he started to make up a group of particles that would be fundamental, such that when put together properly they would form all the hadrons with their various properties. However, he quickly found that in order to do this his new particles must have fractional charges. To Gell-Mann this seemed improbable. Since the days of Faraday everything had been in multiples of a single charge, that of the electron.

He decided to publish anyway in 1963. He said that there would be three fundamental particles and their three **antiparticles**. He called the particles quarks. Baryons would contain three and mesons would contain two particles which are always a quark and an antiquark.

The three types, or flavors, of quarks were called the up quark, down quark and the strange quark or the

u, d and s quarks. The u quark has a charge of +2/3, the d quark of -1/3 and the s quark -1/3. Each quark also has a series of numbers representing various characteristics it conserves. The quarks must be put together such that the hadron they form has all of the various numbers associated with its characteristics. They must also be put together such that the hadron will have a charge of -1, +1 or 0.

For example, a proton is two u quarks and one d quark, with a total charge of +2/3 and +2/3 and -1/3 or +1. A neutron is built of one u quark and two d quarks (+2/3 and -1/3 and -1/3), for a total charge of 0. A positive pion is built from a u quark and a d antiquark (+2/3 and +1/3).

The s quark goes into building the strange particles, which is what gave the s quark its name. It has a charge of -1/3 and a strangeness number of -1 the s antiquark has a charge of +1/3 and a strangeness number of +1. The positive K meson, or kaon, contains a u quark and an s antiquark, for a total charge of +1 and a strangeness number of +1. The negative K meson contains a u antiquark and an s quark for a charge of -1 and a strangeness number of -1.

Later, other more massive particles than the pion or kaon were found that did not fit the quark model with the current quarks. It was theorized and later confirmed experimentally that they contained new flavors of quarks which were called the charm or c quark, the bottom or b quark, and the top or t quark. Now with six quarks scientists can describe all hadrons found so far.

Are there more quarks? As physicists are able to create more massive hadrons will new quarks be found? No one knows for sure. But as particle **accelerators** become more powerful physicists feel that they are coming closer to a truly fundamental particle.

Even though particle accelerators have become more powerful why have we not detected a free quark. Surely if we were to smash a proton and neutron together with enough force we would break them open and find free quarks. And if we can't find them outside a hadron are they really there? What holds them together so tightly? Much of this is explained by a theory called **quantum chromodynamics**.

Scientists at Stanford set up an experiment to try to detect quarks. The sent a beam of high energy electrons through a tank of liquid hydrogen. Many of the electrons went through the hydrogen without hitting anything. But a number of them changed direction in a way that indicated that they had hit something within the proton in the hydrogen nucleus. Here was the first direct evidence that protons were not fundamental particles but, instead, had an internal structure.

Quantum Chromodynamics

Why are the **quarks** so tightly bound inside a hadron? By the early 1970's physicists had a theory suggesting a new interaction. It proposed a new property of matter called "color". Particles such as quarks, it was proposed, had a color property and reacted to this new interaction, called the strong color interaction. The word color in this name is used to distinguish it from the **strong nuclear interaction** which hold hadrons together.

The use of the word color should not be confused with what we know as color. It is just a convenient term to describe how the interaction works. Quarks come in three types, red, green and blue. A combination of each results in an absences of color or whiteness. Every quark combination in hadrons must produce a white result.

Each flavor of quark and antiquark comes in each of the three colors. For example, there is a blue u quark, a red u quark, and a green u quark. There is an anti-blue anti-u quark, an anti-red anti-u quark and an anti-green anti-u quark. In other words in this new theory there are 18 kinds of quarks and 18 antiquarks.

Like real colors, certain combinations of either quark or antiquark colors produce a white, or neutral, result. These combinations are the only ones possible that will produce a hadron. At any instant in a proton, for example, the three quarks will all be a different color. It doesn't mater which color the proton's d quark is as long as the result is neutral. In the case of a meson this is why one quark must always be an antiquark. Green with anti-green, or red with anti-red always produces white.

This explains why there are three quarks to every baryon and a quark/antiquark pair in every meson. These are the only combinations which are colorless. The development of the color theory explained a number of observations that had been anomalous without it.

It was seen that there must be some exchange particle that would account for the strong color interaction. Gell-Mann named it the gluon, another gauge boson. It was the gluon that carried the color property. It had the ability to change the color of quark but not its flavor.

Gluons

Gluons, so named because they are the glue that holds quarks together, were proposed by Gell-Mann. They have properties that are quite different from other gauge bosons. Like a photon it has no mass and its electric charge is zero. It moves at the speed of light and like all bosons has a whole integer spin, which is +1. But unlike other gauge bosons, gluons have the same property that they mediate, namely **color**.

For example, gravitons are exchanged by particles that have mass, but have no mass themselves. Photons are exchanged by particles with electric charge, but have no charge themselves. Gluons, which have color, are exchanged by particles that have color. Therefore gluons can stick to each other. (A pair of gluons that stick together is called a glue ball.)

But, where each quark has only one color at a time each of the eight types of gluons always have two colors. These colors need not be complimentary as do mesons. For example, you could have a blue-anti-red gluon.

Quarks are constantly exchanging gluons, and in doing so are constantly changing their colors. For example, a blue u quark may emit a blue-anti-red gluon and be changed into a red u quark. The red d quark that might absorb this gluon will become a blue d quark. So you see, the flavor of the quark does not change only the color. Therefore the overall color of the hadron remains neutral also even though the quarks did change color.

According to **quantum chromodynamics**, or QCD, the exchange of gluons between quarks prevents them from breaking free of the hadron. Other boson exchanges also keep particles together, but their effects diminish when the distance between particles increases. This is the opposite of what happens when gluons are exchanged. As the distance between quarks increases the number of gluons exchanged increases, which has the effect of increasing the attractive force between the quarks. This is one of the effects of the gluons color charge, called quark confinement, and it explains why quarks have never been seen or isolated.

Quark confinement can be mathematically defined but any attempt to describe it in ordinary language will never represent the true picture because no one can really visualize it. This is true of other quantum phenomena as well. But, some models have been expressed that give some idea about what is happening.

One is called the bag model. In this model hadrons are pictured as tiny bags which contain quarks.

When two hadron bags collide in an attempt to break them open, the two bags instead momentarily form one large bag that contains all the quarks from both hadron bags. The quarks are then jumbled up and then the bag breaks into two or more bags. Each new bag will be a hadron with its quarks still confined as before, although they may be different quarks.

Another model is called the string model. It pictures quarks within a hadron as being attached to each other with strings. If the quarks are close to each other, the strings are slack and the quarks move about freely. But if they are pulled away from each other the strings become taut and the quarks motion is rigidly controlled. The greater the pull on the strings the more tightly the strings hold the quarks.

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Comments:

Glossary

Abundance: The percentage that any particular natural isotope occurs in a sample of an element.

Amphoteric: A compound that reacts as a weak acid or a weak base.

Annihilation: The process that occurs when a particle and an antiparticle meet and their masses are converted into energy in the form of gamma rays.

Antiparticle: For every subatomic particle there is an antiparticle of equal mass but opposite electric charge; for neutral particles suchas te neutron and neutrino, the antiparticle has some other oppsite property to distinguish it.

Atomic number: Atomic number is an experimentally determined number characteristic of a chemical element that represents the number of protons in the nucleus which in a neutral atom equals the number of electrons outside the nucleus.

Atomic radius: Measured in angstroms, it is based upon interatomic distances in the solid state.

Atomic volume: The volume occupied by one mole of atoms of an element. A mole is defined as the gram-formula weight of a substance. The formula weight of a substance is the sum of the atomic weights of all the atoms in the molecule. For example sulfuric acid has a formula weight of 98.1. If you had 98.1 grams of it you would have one mole of sulfuric acid.

Atomic weight: The atomic weight, or mass, of an element is the average relative weight of an element referred to carbon 12 as a standard.

Baryons: Hadrons such as protons and neutrons that have half-integer spin values and are composed of three quarks.

Bosons: Particles, such as the photon and mesons, that have whole integer spin values.

Covalence: The ability to form a bond in which two atoms share a pair of electrons.

Covalent radius: The internuclear distance between atoms in a molecule. It is also known as bond length. Covalent bond lengths may be assigned to pairs of atoms with similar bonds. That is, it is one half the distance between the centers of the two atoms that are covalently bonded.

Density: The mass of a substance per unit volume; for example, how many atoms an object has per cubic centimeter.

Ductile: A substance is ductile if it can be hammered out thin or drawn into a wire.

Electron: An elementary particle that is negatively charged. It is one of the three major particles found in a normal atom and was the first elementary particle to be discovered. It is a lepton.

Electron shell: Any one of the many bands that electrons may occupy in an atom. Only a certain number of electrons may be in any one shell at a given moment.

Electronegative: The tendency to gain electrons; nonmetallic; acid.

Electronegativity: A measure of the attraction of an atom for electrons in its outer shell.

Electropositive: The tendency to lose electrons; metallic; basic.

Element: A substance consisting entirely of atoms of the same atomic number; a substance that can be combined with other elements to form compounds but that cannot be broken down into any simpler substance once it is separated out of a compound.

Fermion: Any particle with a half-integer spin value such as the electron, proton, and neutron.

First Ionization potential: The amount of energy required to remove the most loosely bound electron from an atom.

Gauge Boson: Particles with integer spin values whose exchanges generate the interactions between other particles.

Hadron: Any particle that participates in the strong interaction.

Halogen: Halogen means salt producer. Sea salts are compounds of halogens with metals.

Heat of fusion: The quantity of heat that must be supplied to change a unit mass of a substance from the solid to the liquid state at a constant temperature.

Heat of vaporization: The heat energy that must be supplied to evaporate a unit mass of liquid at a constant temperature.

Hydroxide: Any compound consisting of an element or radical combined with one or more hydroxyl radicals (OH - one oxygen atom combined with one hydrogen atom).

Isospin: A fundamental property of subatomic particles describing the state of rotation of the particle.

Isotope: Two or more species of atoms having the same atomic number (number of protons) but with differing atomic mass number (number of protons and neutrons). In other words they will differ in the number of neutrons in the nucleus. Isotopes have nearly the same chemical properties but may differ in physical properties.

Lepton: Elementary particles with half-integer spin values that participate in the weak and electromagnetic interactions but not in the strong interaction.

Meson: A hadron with an integer spin value composed of a quark and an antiquark; examples are pions and kaons.

Monoatomic: Monoatomic means it occurs as single atoms rather than in pairs or combination.

Muon: An elementary particle, one of the leptons, with a mass more than two hundred times that of the electron. It is also called the mu-meson.

Neutron: An electrically neutral particle, a baryon, that is constiuent of all atomic nuclei except hydrogen-1.

Nucleus: The positively charged core of an atom; consists of one or more protons and, except for hydrogen-1, two or more neutrons.

Oxidation state: The state of an element in a compound with respect to the number of electrons it has

lost or gained, expressed as a positive or negative number indicating the ionic charge of the atom and equal to its valence.

Oxidize: Change the atoms or ions of an element to a higher positive valence by the loss of electrons. An oxidizing agent is an element that can remove electrons from another element.

Particle accelerator: A machine that increases the velocity of charged particles, thus imparting great energies to them.

Period: Each horizontal row in the Periodic Table is called a period. Each period begins filling a new electron shell.

Photon: An elementary particle whose exchange generates the electromagnetic interaction between charged particles; a quantum of electromagnetic radiation.

Pion: The massive particle, about two hundred seventy times as massive a the electron, whose exchange generates the strong nuclear interaction between hadrons.

Positron: The positivly charged antiparticle of the electron.

Proton: A positively charged baryon found in all nuclei of normal atoms.

Radioactive decay: The transformation of subatomic particles into more stable particles; also the transformation of radioactive elements into other elements.

Reduce: Change the atoms or ions of an element to a lower positive valence by the gain of electrons. A reducing agent is an element that can add electrons to another element.

Specific heat: The number of calories of heat required to raise the temperature of one gram of the substance one degree.

Valence: The electrons in the outermost shell of an atom are called its valence electrons.