Second Edition

Instruction Manual

George C. Lisensky, Jill C. Covert, and Ludwig A. Mayer

to accompany the

Solid-State Model Kit

Ludwig A. Mayer and George C. Lisensky

The model kit is based on an original design by
Ludwig Mayer, U. S. Patent No. 4,014,110

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On the Cover: The background photograph of the NaCl structure was taken by John Zimmerman, a SERAPHIM fellow visiting from Wabash College in Crawfordsville, Indiana.

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Preface

The Institute for Chemical Education has a continuing program of publishing pamphlets, books and kits for classroom teachers. This is the third ICE publication that has been inspired by Professor Arthur B. Ellis' Ad Hoc Committee for Solid-State Instructional Materials, and it is by far the most ambitious that we have produced. Developing the kit to the point where it could be published and distributed has involved a great many persons, as can be seen from the acknowledgments on page vi.

This model kit has a long history. A model kit based on the idea of stacking layers of spheres and keeping them in appropriate positions by means of vertical rods was patented by Professor Ludwig Mayer of San Jose State University more than 15 years ago. In 1990 Ludy Mayer came to Madison to participate in the ICE Affiliate program and brought along an example of his model kit, which up to then had not been widely distributed. Professor George Lisensky of Beloit College, Art Ellis and I were all impressed by the ease with which models could be built, even if the builder had no previous knowledge of what the structure ought to look like. George worked out ways to build even more structures, and we offered Ludy an academic-year fellowship under Art's NSF grant to develop the kit further.

During the 1991-92 academic year, Ludy worked with George and others to develop prototype kits, and Ludy sent them for field trials at more than a dozen colleges and universities. Responses from these trials and from other individuals who worked with the kit were incorporated into the current design. At this point, we had a truly excellent way for students to view and study the structures of solids. In my preface to the first edition of the model kit, I stated that the kit's design was not necessarily fixed. The student version is a testament to our continued development. At a considerably reduced cost, this kit will allow students to build most of the structures the original did, and all of them if two kits are combined. The symbol › occasionally found in the directions indicates that more spheres are required than are contained in one student kit. During the 1993–1994 academic year, George prepared the second edition of this manual, adding layer sequences and directions for even more structures.

We welcome your comments about the contents of the kit and the number of structures that can be constructed, the directions for building crystal lattices, the packaging and ease of using the kit with students, the ways in which you have used the kit in your classroom or laboratory, and anything else you think would help us to continue to improve what is already a very fine solid-state model kit. If you have suggestions, please write to me at the address given on the back cover.

The Institute for Chemical Education is grateful for funding from the National Science Foundation Directorate for Education and Human Resources (Grant TPE-91555386), which makes possible dissemination of publications and teaching materials from our headquarters at the University of Wisconsin-Madison. Support for development of the model kit and dissemination of this initial version has been received from the Dow Chemical Company Foundation, the National Science Foundation (Grants USE-9150484 and USE-9254107), and the University of Wisconsin-Madison Office of Outreach Development. Opinions and procedures contained in this and other ICE publications are those of the authors and editors and do not necessarily reflect the policies of the NSF or others who have sponsored this work

I hope that you and your students will find this kit to be interesting and instructive. Please let us know how you like it!

John W. Moore, Director
Institute for Chemical Education
Madison, Wisconsin
May 1994

Preface

The arrangements in space that atoms adopt are the basis of the world around us. Extended crystalline solids, derived from patterns of atoms with seemingly endless repetition, are encountered in myriad common and high-tech contexts. From table salt to silicon and zinc blende, the prototypical semiconductor structures; from the lubricant graphite to perovskite, the basis of the 1-2-3 superconductor structure; and from the mineral fluorite to cesium chloride, a structure possessed by nickel- titanium "memory metal," extended structures are an integral part of our world.

Despite their prevalence, extended structures are notoriously difficult to visualize, a problem that has historically limited their inclusion in many introductory science and engineering courses. Two-dimensional pictures are at a dimensional disadvantage in capturing the essence of these structures, and software packages produced to date lack the tactile component that so directly reveals the spatial relationship of atoms to one another. The objective of the ICE Solid-State Model Kit is to demystify these structures—to make them comprehensible by enabling the user to construct the structures in a layer-by-layer manner that illustrates their structural symmetry.

The Model Kit can be used to build over 80 different structures that would commonly be discussed in science and engineering courses. A pair of bases makes it possible to visualize many of the structures from two complementary geometric perspectives—sitting on the face of a cube and on its body diagonal, for example. And natural cleavage planes possessed by many of the solids are easily located by lifting one sphere and watching others be carried along.

The Model Kit serves as part of the infrastructure for an effort, supported by the National Science Foundation, the American Chemical Society, and the Camille and Henry Dreyfus Foundation, to integrate materials chemistry into the chemistry curriculum. Many of the structures that can be constructed with this Kit are discussed in “Teaching General Chemistry: A Materials Science Companion,” which was published by ACS Books in 1993.

While many individuals contributed to the realization of this Kit, it is my pleasure, on behalf of the Ad Hoc Committee for Solid-State Instructional Materials, to acknowledge especially the creative talents and energy of Ludwig Mayer and George Lisensky, who developed the methodology for building the structures in the Kit and devised implementation strategies for producing the Kit; John and Betty Moore, who provided technical guidance and made resources from ICE available for this project; Jill Covert, Margret Geselbracht, Krista Moore, Donald Neu, Joel Olson, Raymond Smith, and Christy Cargille who assisted with the preparation and production of the Kit; The Dow Chemical Company Foundation, the National Science Foundation, and the University of Wisconsin-Madison Office of Outreach Development, which provided crucial seed funding; and finally, the many teachers and students around the country who auditioned the Kit and whose comments have greatly enhanced its effectiveness.

We hope that you enjoy and learn from the Kit, and we welcome your comments and suggestions.

Arthur B. Ellis
Chair, Ad Hoc Committee for Solid-State Instructional Materials

About the Kit

Safety

Please exercise normal care in handling metal rods and plastic bases, which, if misused, could cause damage. The kit should be kept away from small children, who might accidentally ingest the spheres or spacers.

Protecting Your Kit

Use and store the kit in a dry environment: water could damage the cardboard box and templates; organic solvents can attack the plastic containers, bases, spacers, and spheres in the kit itself.

Before Using Your Kit

* *Make sure that the templates are free of hole punch-outs. If some remain, use a rod from the kit to push them out; this prevents the punch-outs from being pressed into and plugging the base holes during use.*

Replacement/Extra Parts

In the future, ICE plans to be able to provide replacement/extra parts for a fee. Improvisation, however, is also possible. For example, if additional spacers are needed, soda straws can be cut to the appropriate size. If templates are needed, there are illustrations in the manual that can be copied.

Allowed Uses

Since some users may wish to incorporate the directions for building a model into their own written materials for students, permission is hereby granted for such use, provided that it is for local, non-commercial distribution. Anyone considering for-profit reproduction of any of these images or of the model-building directions must obtain written permission from the Institute for Chemical Education.

Checking the Model

An Illustrated Structure Guide (92-004A; $6) is available from ICE. This booklet contains computer-generated illustrations of some of the structures that can be built using the Instruction Manual. Since these images are static, they do not serve as a substitute for the models; to see all features of a structure, the model must be built.

A selection of structures that can be displayed and rotated using the MacMolecule program on a Macintosh computer has been prepared by Ludwig Mayer, Department of Chemistry, San Jose State University, San Jose, CA 95192–0101. These structures have been published in *JCE: Software*, Vol. 6C, No. 1, together with the MacMolecule program. (Contact *JCE: Software*, Dept. of Chemistry, Univ. of Wisconsin–Madison, 1101 University Ave., Madison, WI, 53706, for ordering information.) MacMolecule (by Eugene Myers and Carlos Blanco, Department of Computer Science, and Richard B. Hallick and Jerome Jahnke, Departments of Biochemistry and Molecular and Cellular Biology, University of Arizona, Tucson, AZ 85721) and the structures can also be obtained by anonymous FTP at joplin.biosci.arizona.edu.

Living Product

We encourage the development of new structures. To assist, we have included blank templates in the manual appendices. If you devise new structures, let ICE know, and we will try to include the structures in future editions.

Acknowledgments

Funding

We are grateful for funds from the National Science Foundation (Undergraduate Course and Curriculum Development Program, Grants USE-9150484 and USE-9254107, and the Division of Materials Research), The Dow Chemical Company Foundation, University of Wisconsin-Madison Office of Outreach Development, The Camille and Henry Dreyfus Foundation, American Chemical Society, San Jose State University, and the Institute for Chemical Education.

Individuals

We thank Susan Hixson, David Nelson, Robert J. Reynik, Robert Watson, and Gene Wubbels of NSF; Robert Lichter of the Dreyfus Foundation; Tom Kennedy, Bob Nowak, Ted Tabor, and Warren Knox of The Dow Chemical Company; Pat Takemoto, Joe Corry, Al Wortley, and Peg Geisler of the UW-Madison Office of Outreach Development; Joe Casey of the Milwaukee Area Technical College; and Jeroen Rietveld, Glen Dirreen, Don Neu, Joel Olson, Krista Moore, Margret Geselbracht, Rona Penn, John Moore, Betty Moore, Natasha Aristov, Lynn Hunsberger, Al Behling, Harlan Friske, Christy Cargille, Jill Covert, Jill Banfield, Gene Wubbels, Ray Smith, Jack Kotz, Bill Robinson, Mike Humphry, Susan Trebach, and Art Ellis for their help.

Special thanks to Joel Olson for drawing the layer-by-layer sodium chloride pictures used in the Getting Started section.

Field Trials

Earlier versions of the Model Kit were used in field trials by the following individuals: Stan Whittingham (SUNY Binghamton), Mark Muyskens (Calvin College), Sandra Laursen (Kalamazoo College), Dean Waldow (Augustana College), Phil Welty (Edgewood College), Andrew Bocarsly (Princeton University), John Hostettler (San Jose State University), Steven Drew (Carleton College), Alex Williamson (North Carolina A&T State University), Kenton Whitmore (Rice University), Gerald Van Hecke (Harvey Mudd College), Wade Killingsworth (Ohlone Community College), Brock Spencer, Laura Parmentier (Beloit College). We thank these individuals for their helpful comments and suggestions.

Contents

4) Close-packed Structures with Octahedral Holes Occupied (Continued)

5) Close-Packed Structures with Tetrahedral Holes Occupied

6) Other Interesting Structures

* *This instruction manual is designed for use with both the Deluxe and Student Model Kits distributed by ICE. The primary difference between the two kits is the number of spheres included. The symbol ② occasionally found in the directions indicates that more spheres are required than contained in one Student Kit. Either use a Deluxe Kit or combine the contents of two Student Kits.*

Getting Started

This kit will allow you to build models of a great many crystal structures, even if you do not yet know where the atoms or ions are located in those structures. By examining the models you can learn where atoms are located and how to visualize three-dimensional crystal lattices from unit cells. The model kit makes complex structures easy to build and see.

* **To get started, open the box and examine the parts, identified and shown actual size on pp. 2–3. Read and master the introductory materials on pages 2–7: Model Kit Parts, What You Need to Know, Key to the Directions, and NaCl Example. Then you are ready for the next step, building a model with condensed directions.**

How to Build a Model Using the Condensed Directions

To build a structure using the condensed directions on pages 8–103 in this manual:

- identify the **structure** you want to build—or that has been assigned
- find the page of the **manual** with directions for that structure—check Contents or Index
- get out the paper **template** that is indicated in the directions
- get out the plastic **base** whose corner mark matches the template corner mark
- align all the **holes** of the template over some of the base holes
- insert **rods** into the template holes identified in the directions
- check the key for that page to see which **spheres** and **spacers** are used, shown actual-size in the directions and indicated by different type styles
- build each layer in numerical order by sliding the spheres and spacers down the rods with that type style number next to them in the **pattern**
- finish by repeating the first layer

If your paper templates have green and yellow dots...

In earlier model kits, the templates were marked with yellow and green dots.

The symbol **|** used in these directions corresponds to the green dot.

The symbol **W** should be matched with the yellow dot.

Templates *P*, *Q*, and *R* have been changed and will affect the building of some structures. Make these changes if you wish to use the old green and yellow dot templates with this manual:

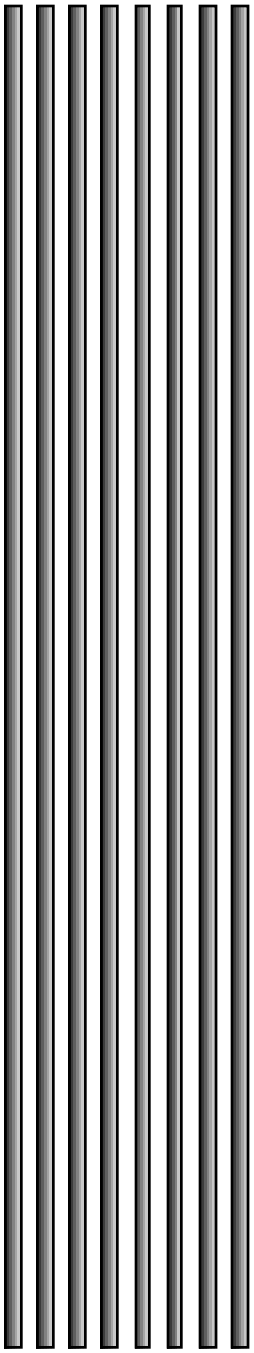
- Graphite: Use the circled holes of old template *R*.
- H_2O, Tridymite, Silicates: Use the dashed-line connected holes of old template *R*.
- Corundum: Use old template *J*.
- Rutile: Use the back side of old template *P*.

Model Kit Parts*

Spheres (polymer with center hole)

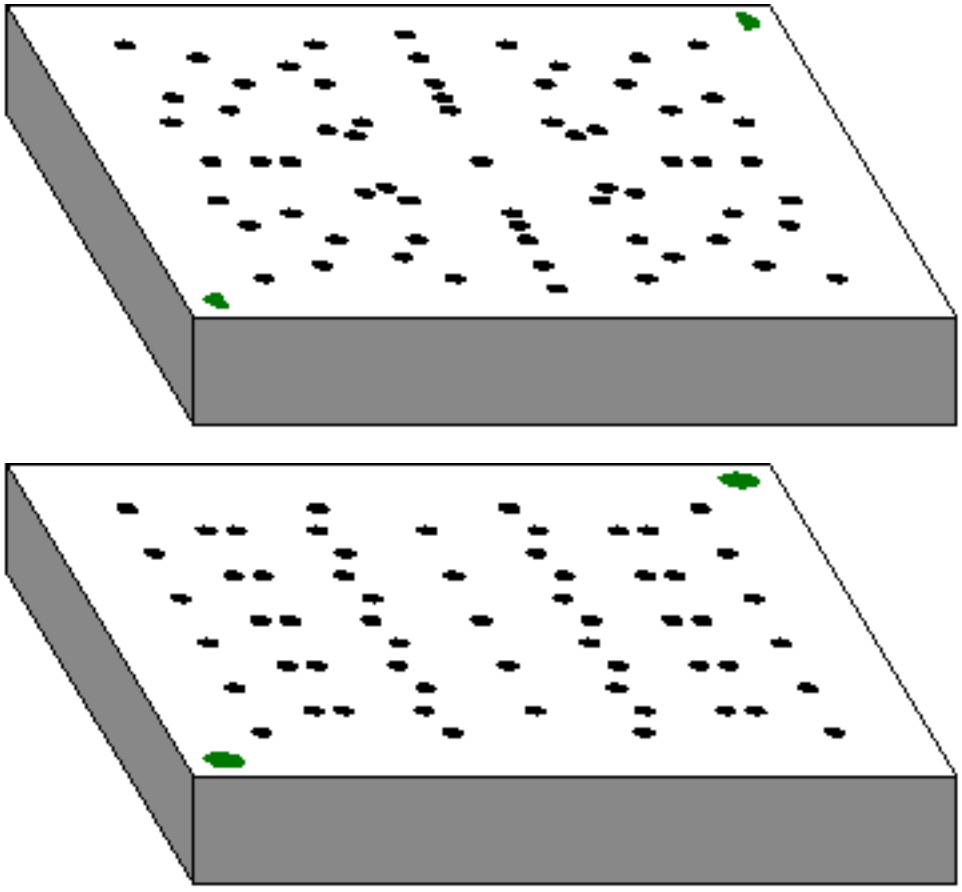
Sometimes more than one color of a given sphere size is required. A distinguishing stripe or color may be added to the spheres in the kit using a Sharpie permanent marker and later removed using 95% ethanol.

Rods (metal)



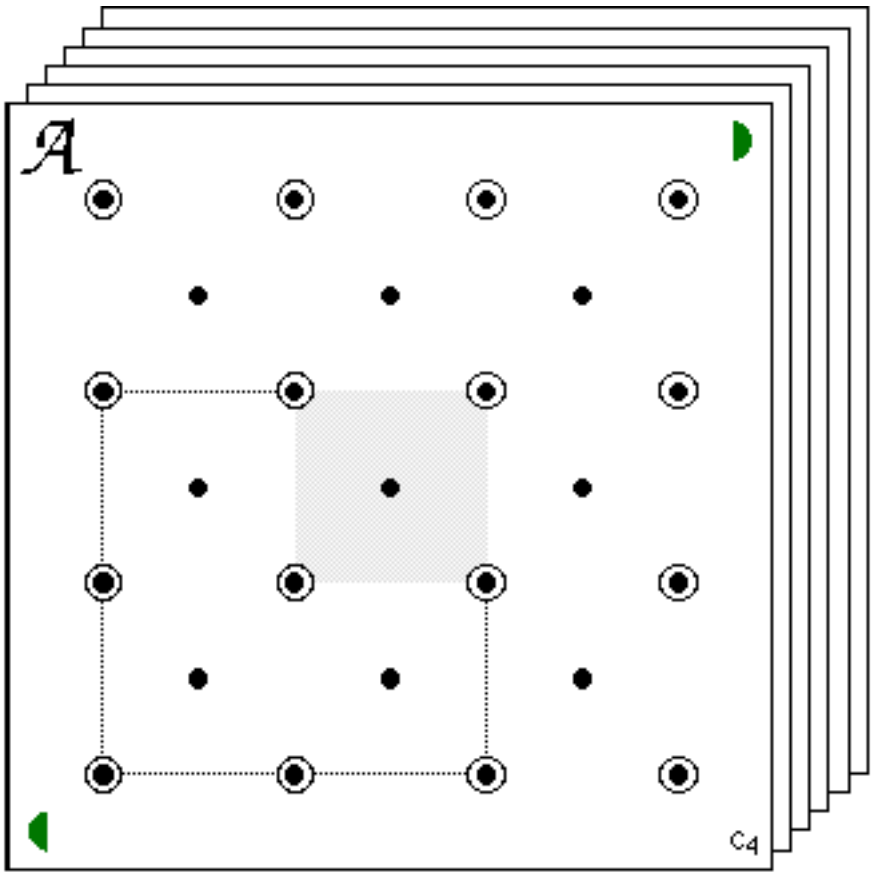
Bases (polymer)

The two bases are distinguished by l or waffixed to one corner.



* Parts are shown actual size.

Templates (cardboard)



All templates are shown beginning on page 110.

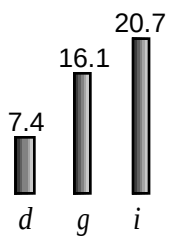
* *Make sure that the templates are free of hole punch-outs. If some remain, use a rod from the kit to push them out; this prevents the punch-outs from being pressed into and plugging the base holes during use.*

Spacers (plastic tubes)

About 60% of the models in this manual do not require any spacers. When spacers are required, the plastic tubing supplied will need to be cut to the appropriate length for a given structure.

The spacers are shown actual size in the template key; the numbers above the spacers are the required length of the spacer in millimeters. The letters below some of the spacers are included for compatibility with earlier versions of the model kit.

It may be helpful to keep a supply of the most commonly used sizes (shown at right) needed to build a dozen structures. The other spacer sizes are used for only a few specific structures. A complete listing of sizes is shown actual size on page 123.



What You Need to Know

Begin by reading and understanding these facing pages, which contain general, but detailed instructions. Then build a NaCl unit cell using the step-by-step instructions here and illustrated on pp. 6–7. Once you have successfully worked your way through this example, you are well on your way to mastering this Kit, and you will find the condensed directions throughout the rest of this manual give you sufficient information for building other model structures.

Each structure and its directions for building are conveniently described on a single page. An annotated sample appears on the next page. To build a structure, follow these steps:

- First obtain the proper **template** (*A*, *B*, *C*, etc. shown in the upper right corner of the page) and place it on a **base** having the same-corner mark (l or w) as the template. Make sure the base corner mark and one of the template corner marks are in the same corner, and align the template so that base holes can be seen through each template hole. (The NaCl example uses the wbase.)

- Follow the instructions which have bold-faced words describing the **holes** to be used for **rods**. Insert a rod in each of the designated holes. (In this NaCl example, all 9 holes in the shaded region are used. Other structures might require only the circled holes of the template.) There are directions for building a unit cell or hexagonal section, and also for building more than that.

- Choose the **spheres** and **spacers** to be used, as shown at actual size in the key at the bottom left. Each sphere or spacer has its own type style shown next to it. You may need to cut the spacer tubing to the specified length. (NaCl uses the large colorless spheres, blue spheres, and 7.4 mm spacers.) The symbol › occasionally found in the directions indicates that more spheres are required than contained in one Student Kit.

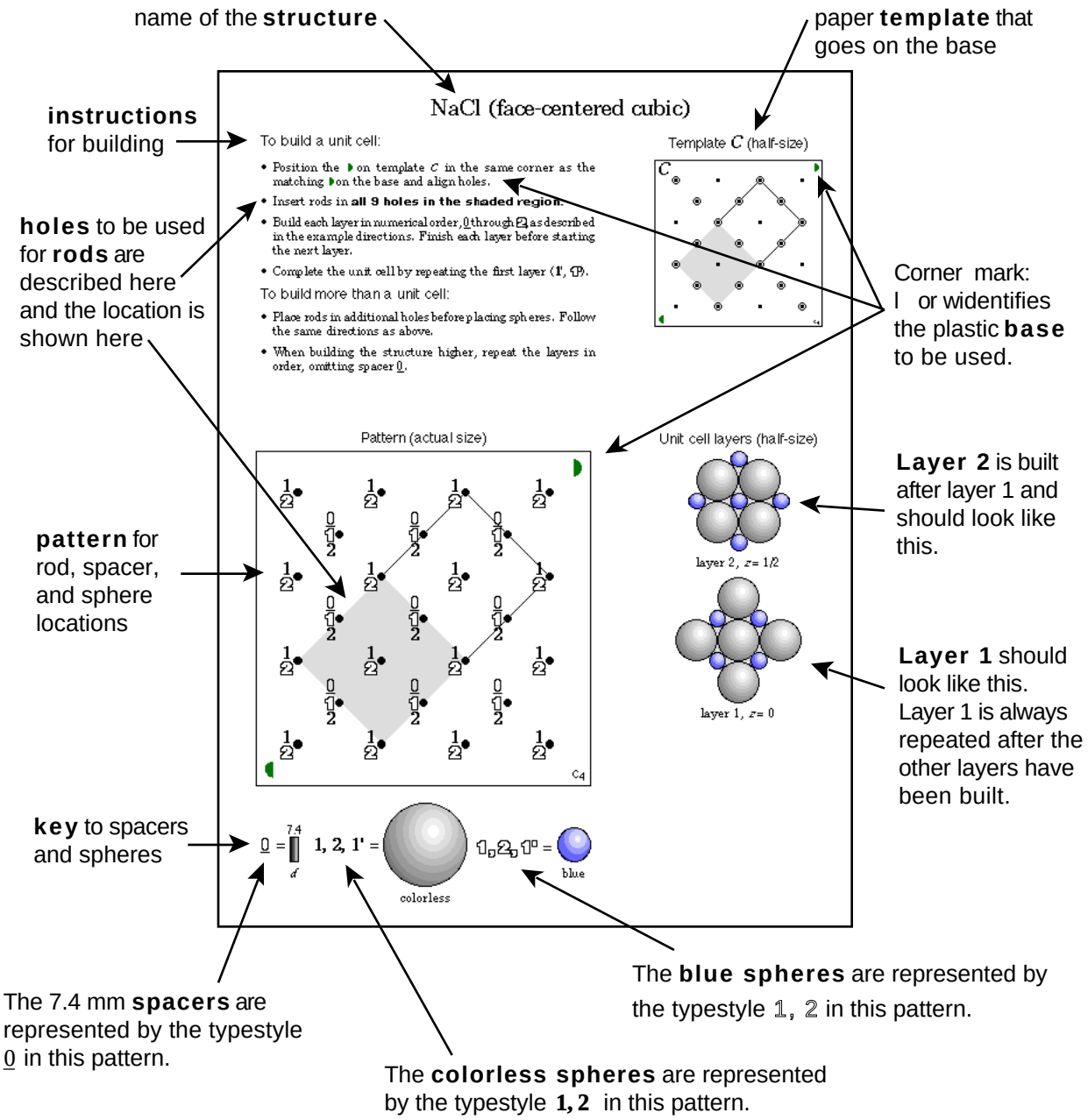
- In numerical order, slide the spacers and spheres down the rods to form layers. Follow the full-sized **pattern** at the center left, which uses type-styled numbers to show rod locations for each sphere and spacer size. For the NaCl pattern:

  0 means the 7.4 mm spacers are needed to support the first layer, each place that a 0 appears.
  1 means the colorless sphere is in the first layer, each place that a **1** appears.
  1 means the blue sphere is in the first layer, each place that a 1 appears.
  2 means the colorless sphere is in the second layer, each place that a **2** appears.
  2 means the blue sphere is in the second layer, each place that a 2 appears.

  For this example, begin with 0 (for the spacers), then place the **1** and 1 spheres, then the **2** and 2 spheres. Since the numbers only go to 2, there are only two different kinds of layers in the structure. After building all the layers, always repeat the first layer on top of the other layers using the spheres noted with **1'** and 1' to complete the unit cell. To build more of the structure, continue by repeating layer 2.

- Check your structure by comparing it with the **unit-cell layers** that appear at the right of the page. These show a view of each sphere layer. The fractional unit cell coordinate of the vertical height, $0 \le z \le 1$, is given for most layers.

Key to the Directions



Taking a Model Apart

* *To take a model apart, invert the structure and allow the spheres to slowly slide off the rods. Remove the rods by grasping near the base and pulling without bending or wiggling.*

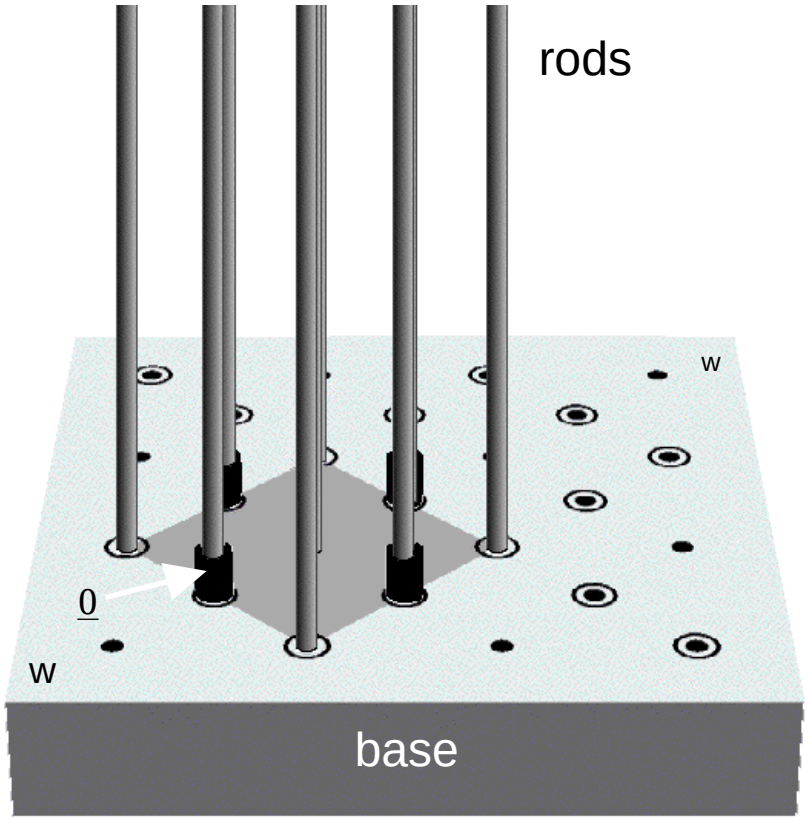
NaCl Example

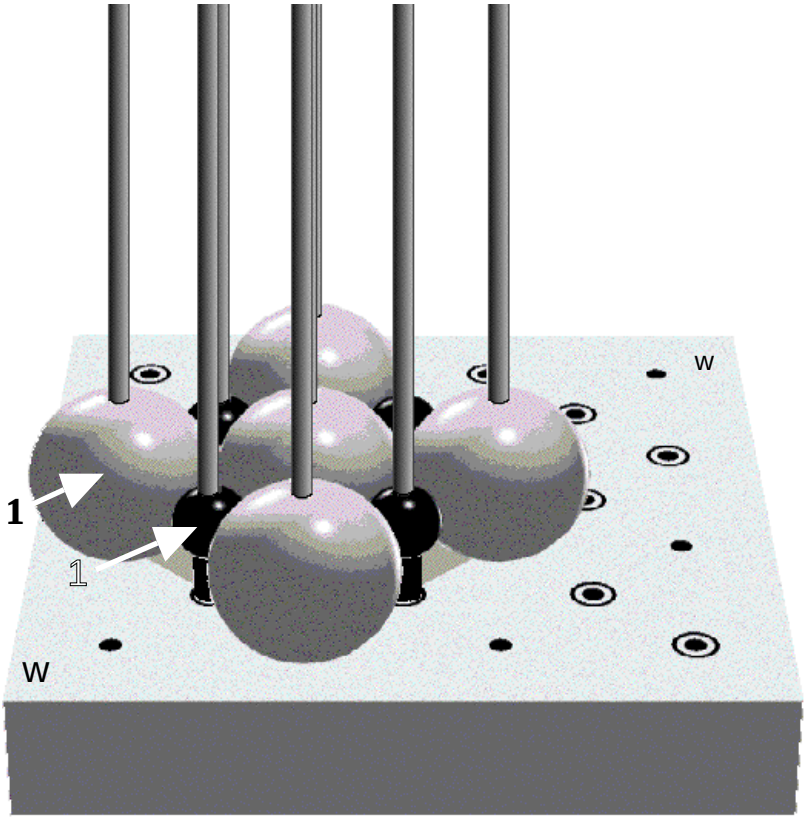
Having read pp. 4–5, you are now ready to follow the directions on p. 33.

Place template *C* on the base with the corner mark in the same corner as the matching corner mark on the base (W in this case). Align the template so that the base holes can be seen in each of the template holes.

Insert a rod in each of the nine holes in the shaded region of the template.

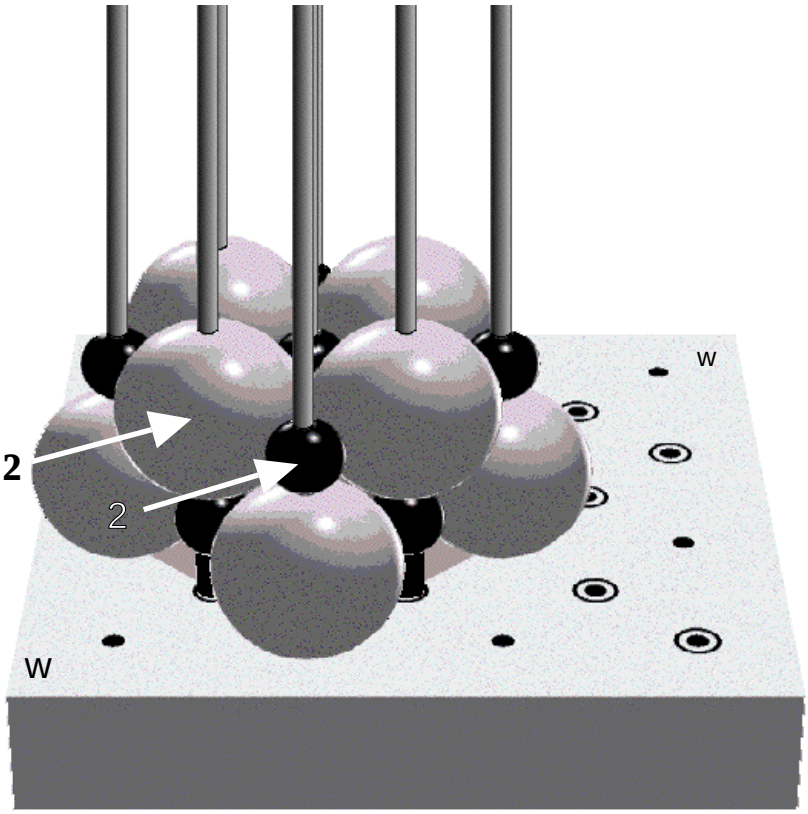
Build layer 0 by sliding 7.4 mm-long spacers down each of the rods marked 0 in the pattern. (Layer 0 spacers are needed to support the first layer of spheres.)

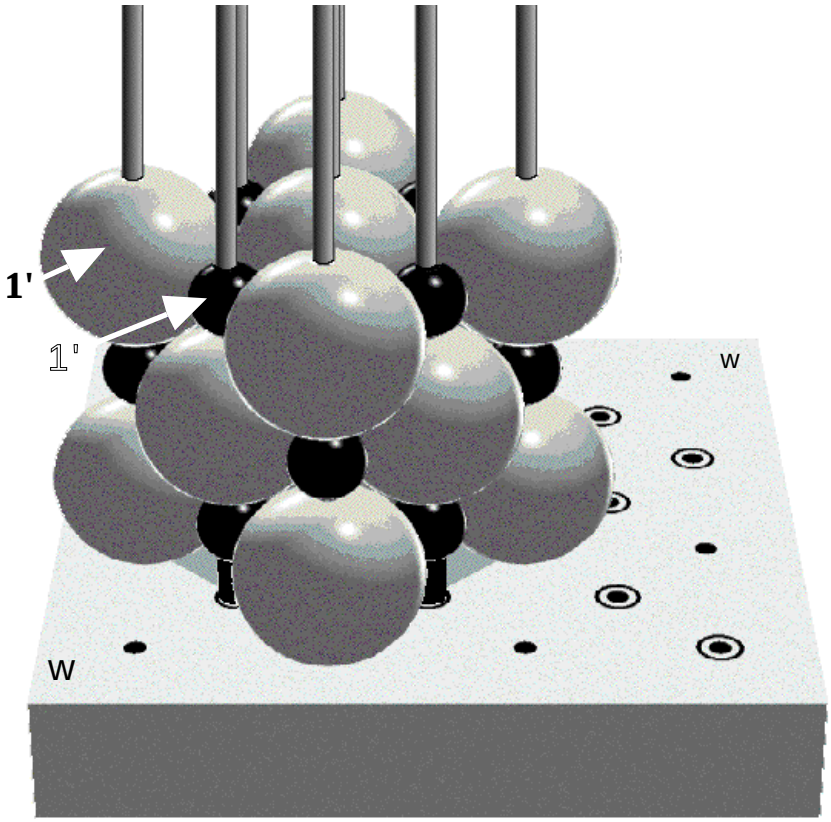




Build layer 1 by sliding large, colorless spheres down each rod that has a **1** next to it in the pattern and by sliding smaller, blue spheres down each rod with a 1 next to it in the pattern.

Build layer 2 by sliding large, colorless spheres down each rod with a **2** next to it in the pattern and by sliding smaller, blue spheres down each rod with a 2 next to it in the pattern.





Since the numbers in the pattern only go up to 2, there are only two kinds of layers in the unit cell.

To finish the unit cell, repeat layer 1. The **1'** and 1' next to the spheres in the pattern key serve as a reminder.

Again, slide a large, colorless sphere down each rod with a **1** next to it in the pattern and slide a smaller, blue sphere down each rod with a 1 next to it in the pattern.

You have now completed one unit cell of NaCl and are ready to build any of the structures in this manual using the condensed directions.

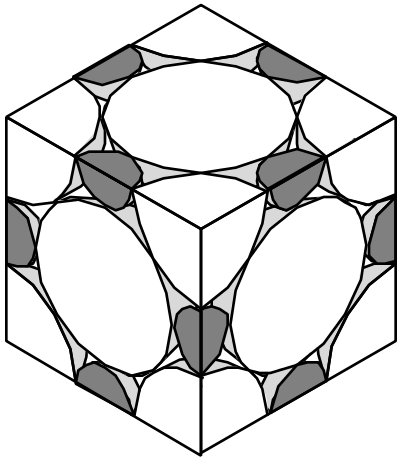
Packing Schemes and Structures

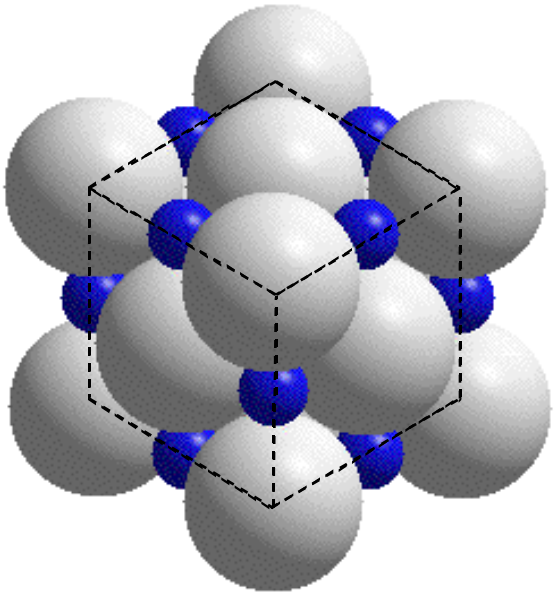
This section contains the directions for building over 80 different models. The classification into the first five categories of models depends on the packing of the largest spheres, even if more than one element occupies the packing positions or if some of the positions are vacant. For example, BiF_3 would be body-centered cubic if it contained only one element so it is classified as a body-centered cubic related structure. Diamond is viewed here as a body-centered cubic structure with half the atoms missing (compare with NaTl) rather than the more traditional view as an expanded face-centered cubic structure with new layers inserted between the face-centered cubic layers.

1) Primitive Cubic and Related Structures
2) Body-centered Cubic and Related Structures
3) Close-packed Structures
4) Close-packed Structures with Octahedral Holes Occupied
5) Close-packed Structures with Tetrahedral Holes Occupied
6) Other Interesting Structures

Models, Unit Cells, and Unit Cell Contents

Because the spheres supplied in the ICE Solid-State Model Kit cannot be divided into fractions, the kit cannot be used to construct a structure's unit cell without having parts of some spheres extend outside the actual unit cell. The directions "to build a unit cell" will actually build the smallest collection of spheres and layers that *contains* a single unit cell. The difference between a unit cell, which can be repeated by moving it parallel to its edges by the length of an edge to generate an entire crystal structure (without overlapping), and the model built on the previous page can be seen by comparing the two figures below.





NaCl Unit Cell (above)
Model Kit "Unit Cell" (right)

For additional information on unit cells and for using unit cells to illustrate stoichiometry and empirical formulas, see Chapter 3 of "Teaching General Chemistry: A Materials Science Companion," A.B. Ellis, M.J. Geselbracht, B.J. Johnson, G.C. Lisensky, and W.R. Robinson, ACS Books, Washington, D.C. (1993).

Primitive Cubic

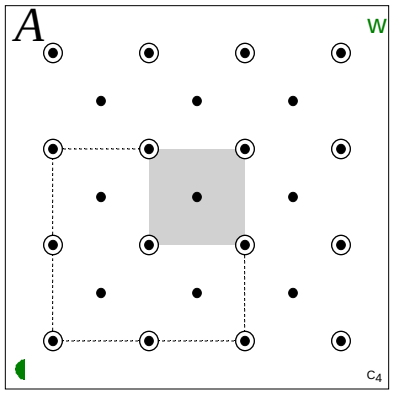
To build a unit cell:

- Position the won template *A* in the same corner as the matching won the base and align holes.
- Insert rods in the 4 circled holes in the shaded region.
- Build layer **1** first as described in the example directions.
- Complete the unit cell by repeating the first layer (**1'**).

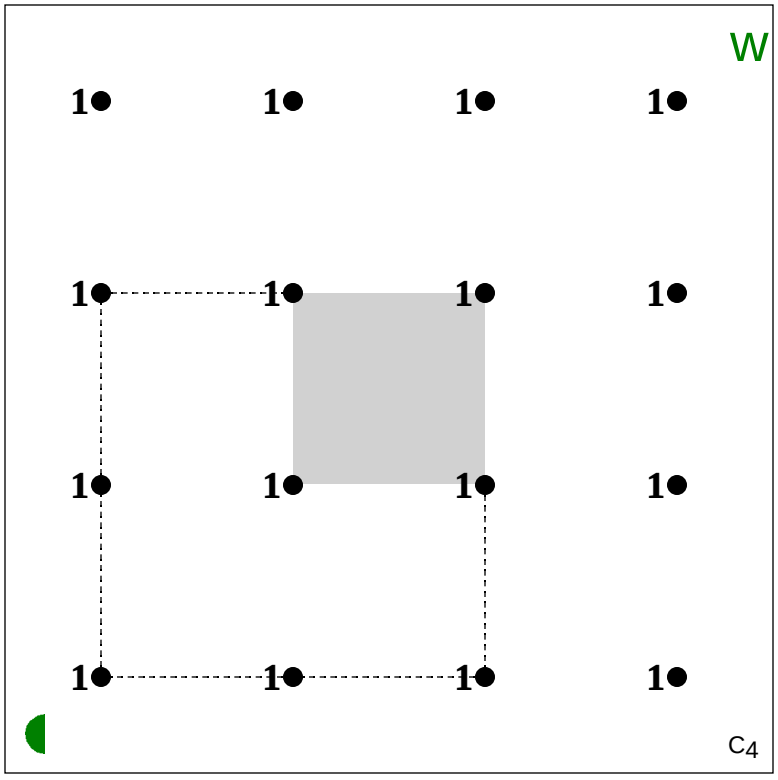
To build more than a unit cell:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

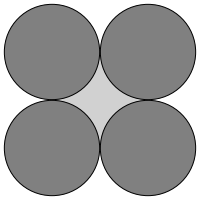
Template *A* (half-size)



Pattern (actual size)

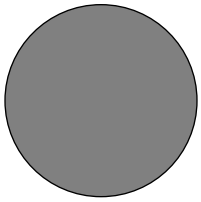


Unit cell layers (half-size)



layer 1, *z* = 0

1, 1' =



colorless

Primitive Cubic (body diagonal)

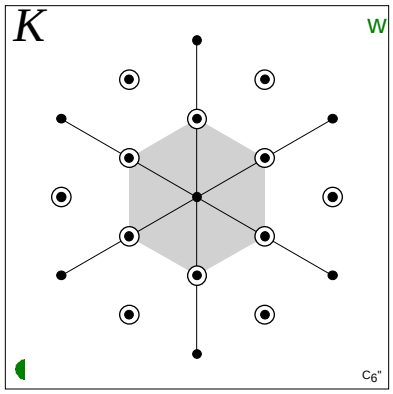
To build a unit cell:

- Position the won template K in the same corner as the matching won the base and align holes.
- Insert rods in all 7 holes in the shaded region.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

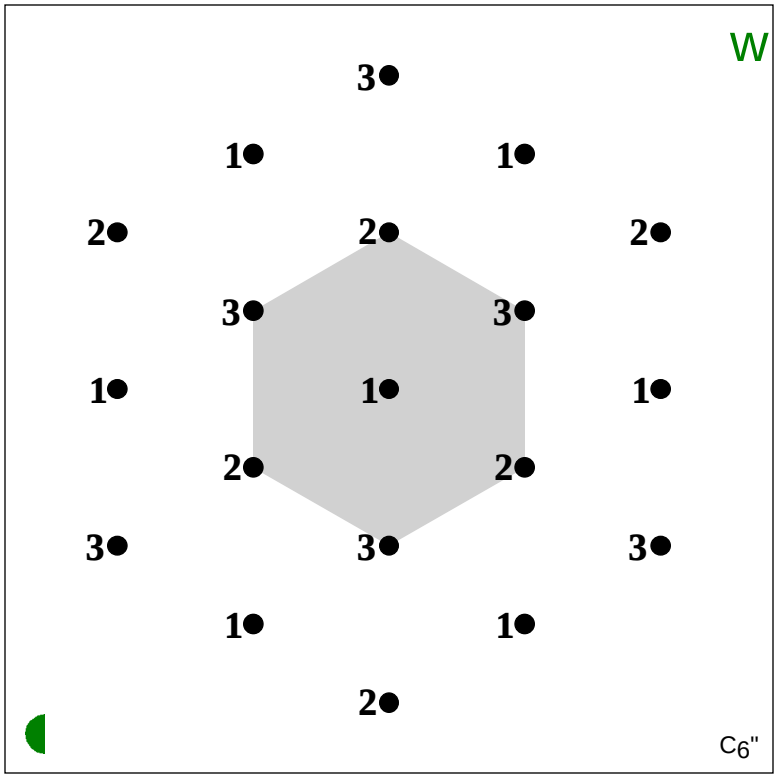
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

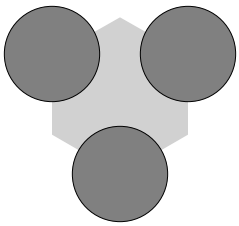
Template K (half-size)



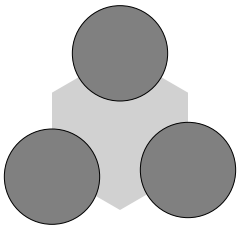
Pattern (actual size)



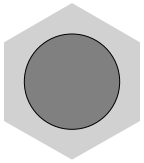
Unit cell layers (half-size)



layer 3, z = 2/3

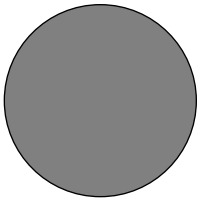


layer 2, z = 1/3



layer 1, z = 0

1, 2, 3, 1' =



colorless

CsCl

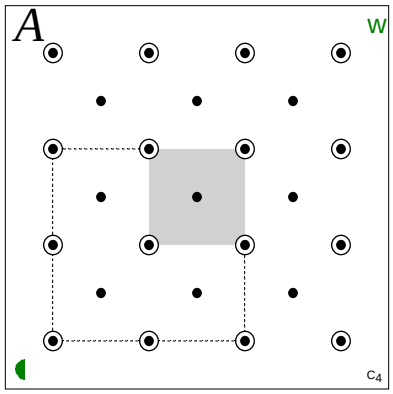
To build a unit cell:

- Position the won template *A* in the same corner as the matching won the base and align holes.
- Insert rods in all 5 holes in the shaded region.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

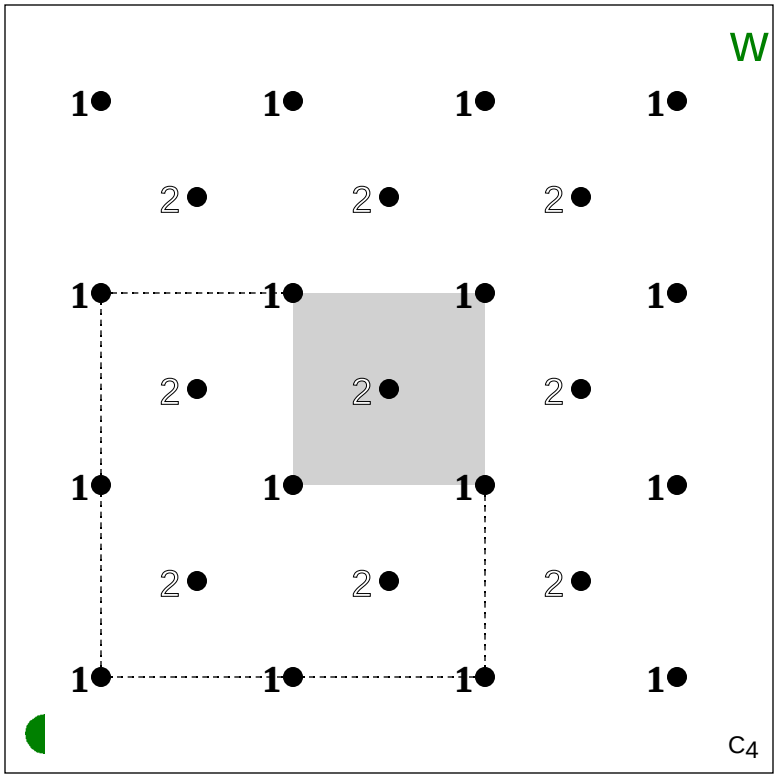
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

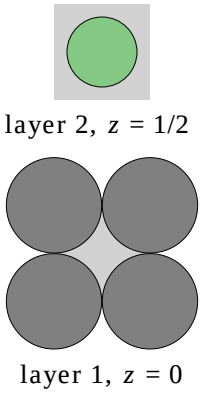
Template *A* (half-size)



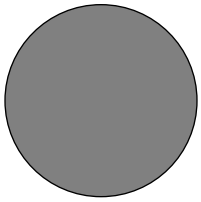
Pattern (actual size)



Unit cell layers (half-size)

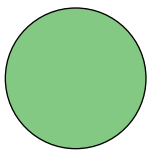


1, 1' =



colorless

2 =



green

CsCl (alternate)

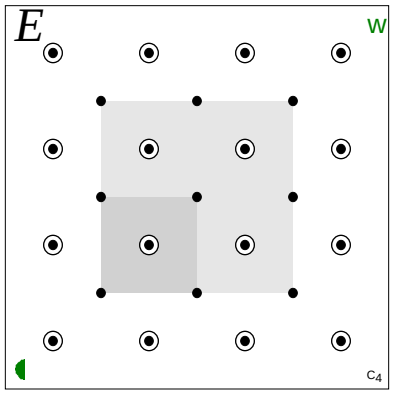
To build a unit cell:

- Position the won template E in the same corner as the matching won the base and align holes.
- Insert rods in all 5 holes in the small shaded region.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

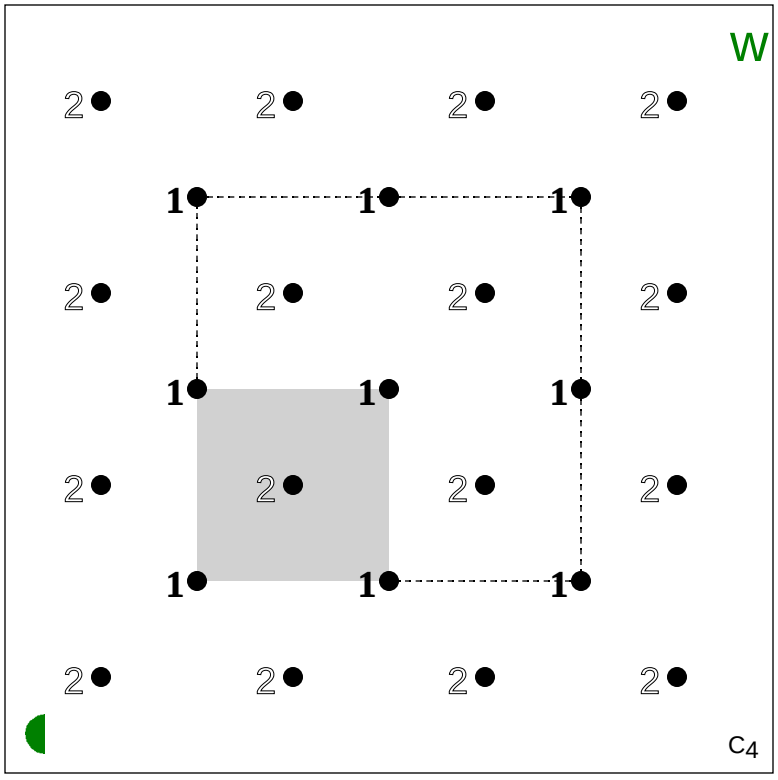
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

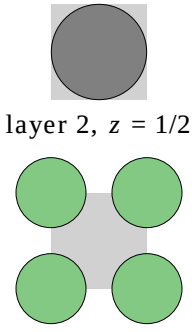
Template E (half-size)



Pattern (actual size)



Unit cell layers (half-size)



layer 2, z = 1/2

layer 1, z = 0

2 =

colorless

1, 1' =

green

CsCl (body diagonal)

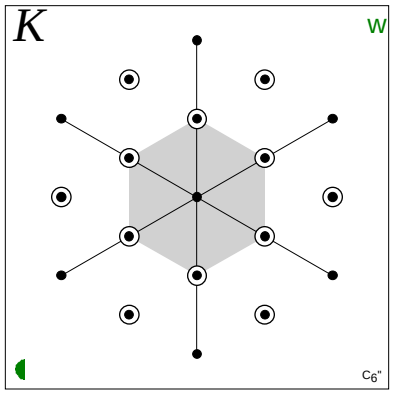
To build a unit cell:

- Position the w on template K in the same corner as the matching w on the base and align holes.
- Insert rods in all 7 holes in the shaded region.
- Build each layer in numerical order, **1** through 6, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

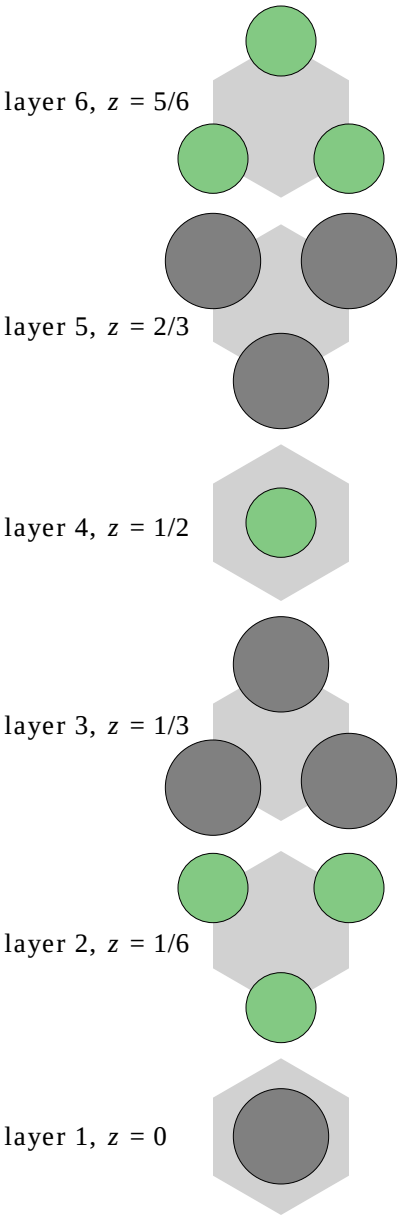
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

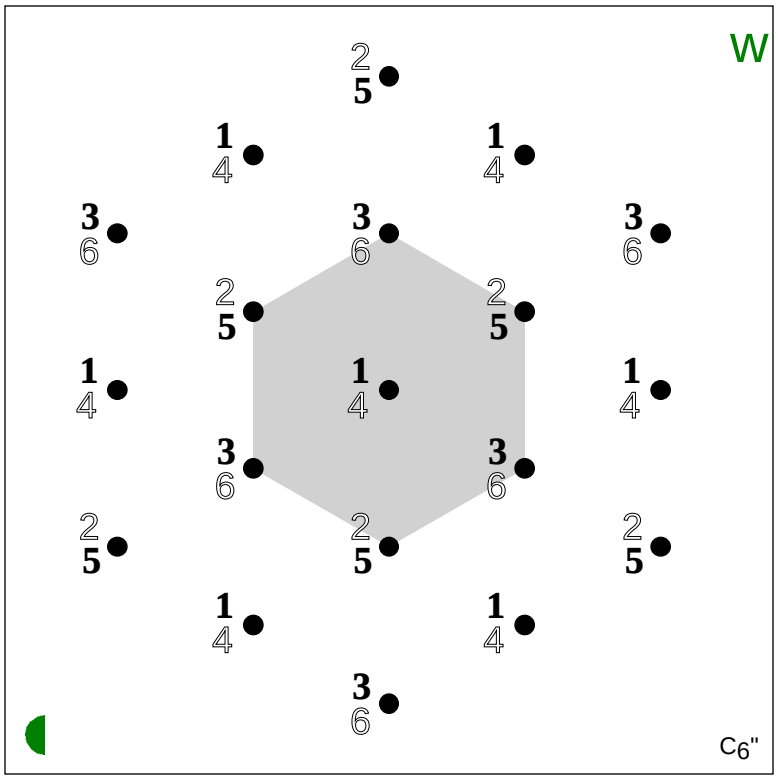
Template K (half-size)



Unit cell layers (half-size)



Pattern (actual size)



1, 3, 5, 1' = colorless

2, 4, 6 = green

Fluorite

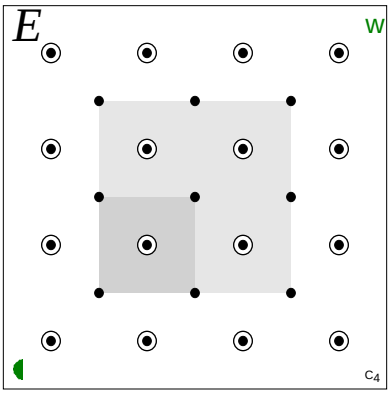
To build a unit cell:

- Position the won template E in the same corner as the matching won on the base and align holes.
- Insert rods in all 13 holes in the entire shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

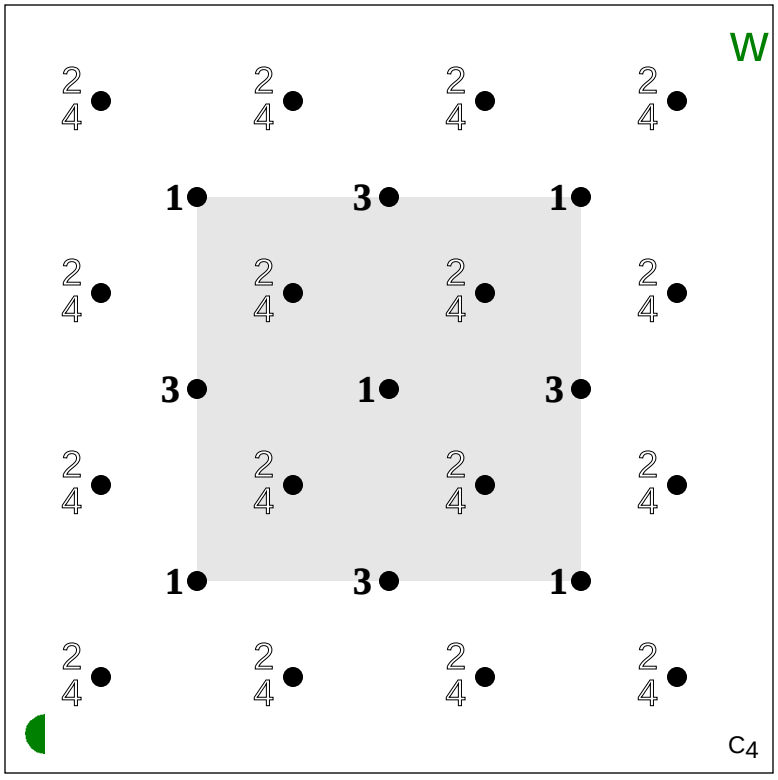
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

Template E (half-size)



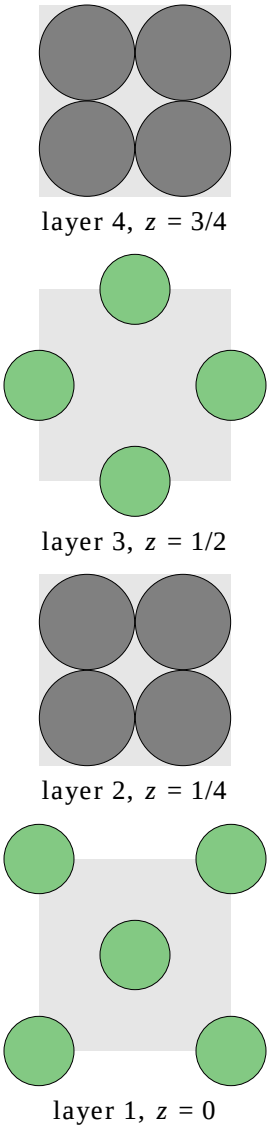
Pattern (actual size)



2, 4 = colorless

1, 3, 1' = green

Unit cell layers (half-size)



layer 4, z = 3/4

layer 3, z = 1/2

layer 2, z = 1/4

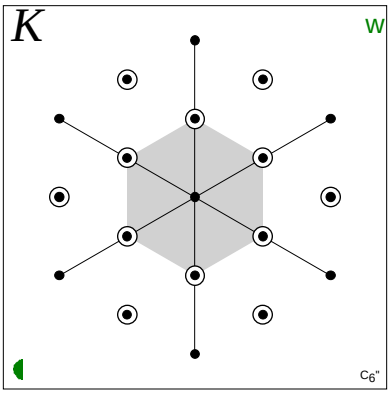
layer 1, z = 0

Fluorite (body diagonal)

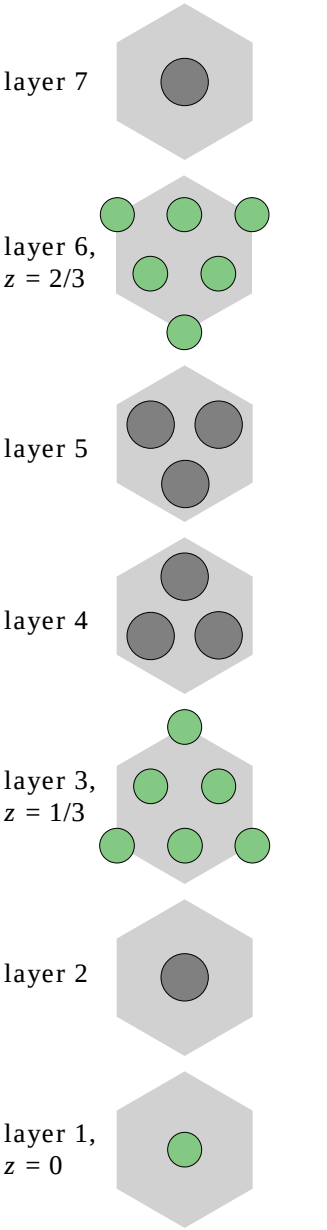
To build a unit cell:

- Position the won template K in the same corner as the matching won the base and align holes.
- Insert rods in the 13 line-connected holes.
- Build each layer in numerical order, 0 through 7, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

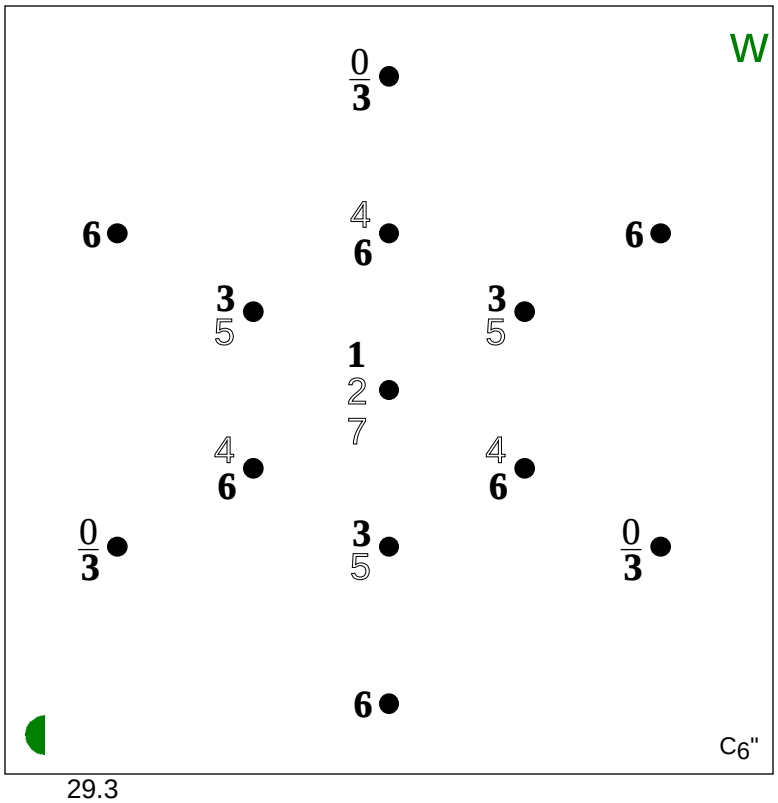
Template K (half-size)

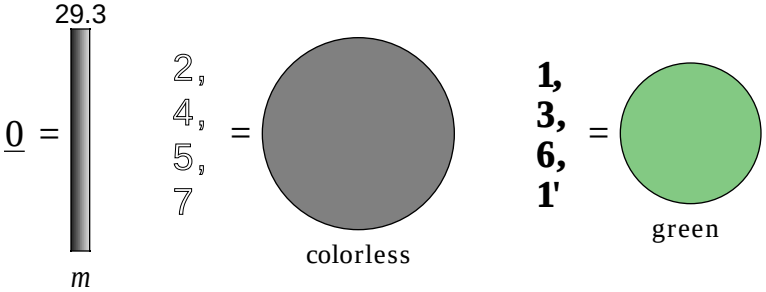


Unit cell layers (quarter-size)



Pattern (actual size)





Fluorite (alternate)

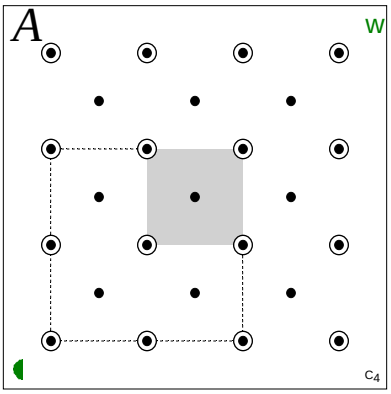
To build a unit cell:

- Position the won template *A* in the same corner as the matching won the base and align holes.
- Insert rods in all 13 holes in the dash-enclosed square.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

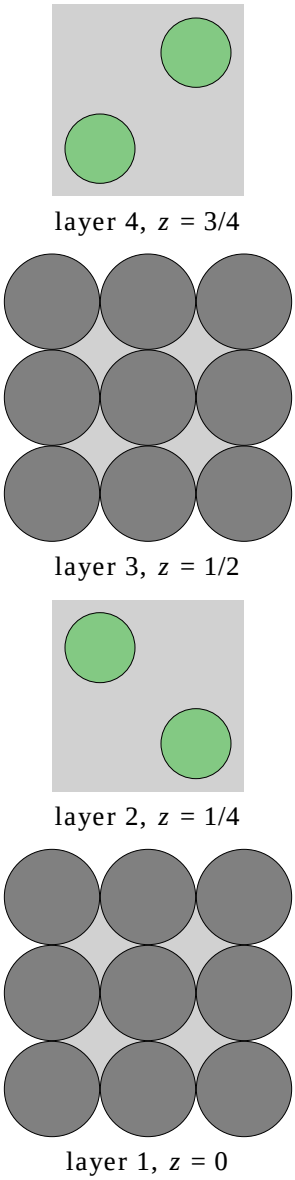
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

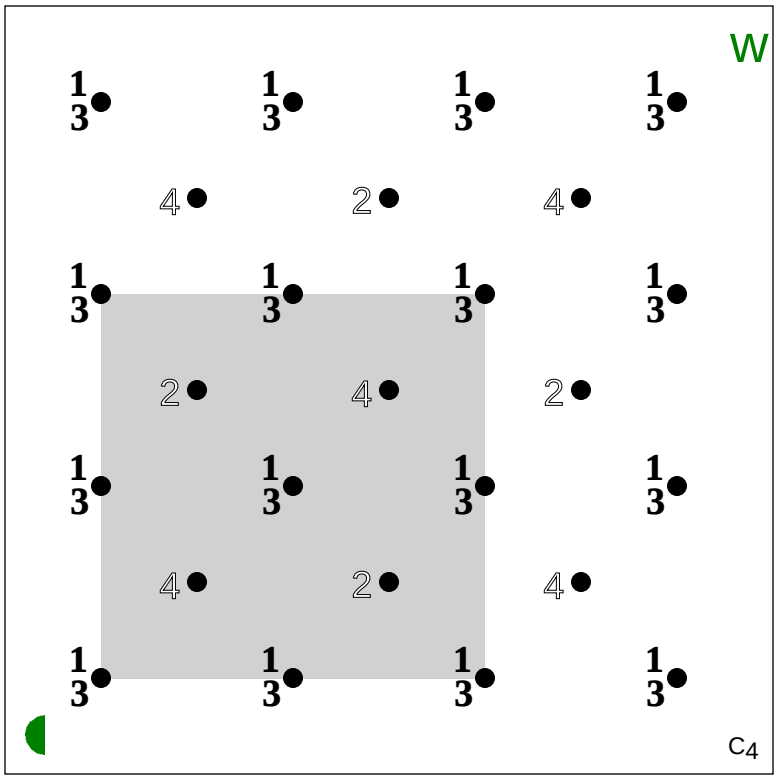
Template *A* (half-size)



Unit cell layers (half-size)



Pattern (actual size)



1, 3, 1' = colorless

2, 4 = green

K_2PtCl_4

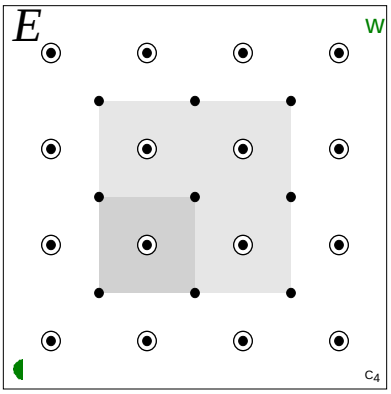
To build a unit cell:

- Position the won template *E* in the same corner as the matching won the base and align holes.
- Insert rods in 12 holes in the entire shaded region.
- Build each layer in numerical order, 0 through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

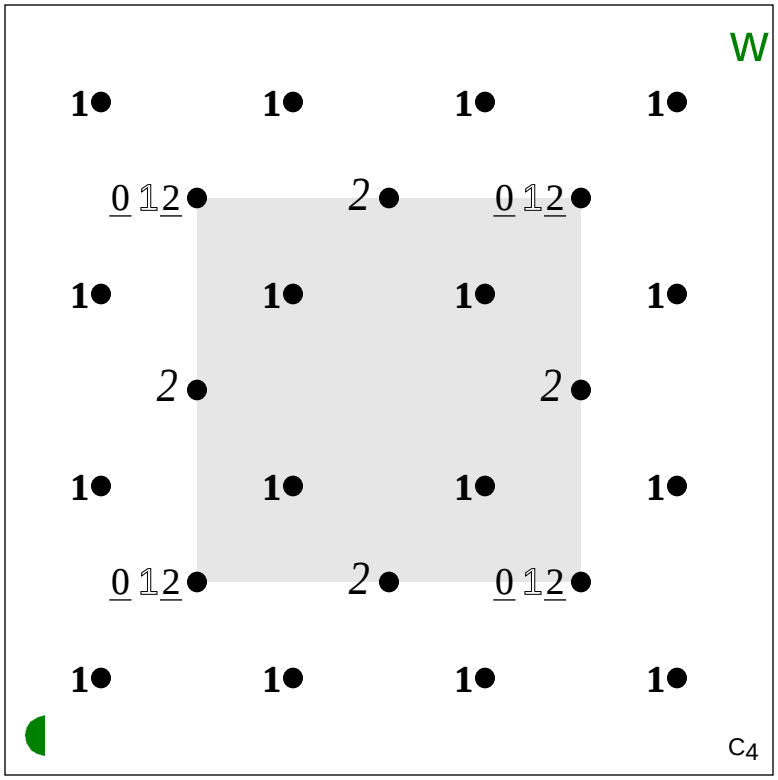
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

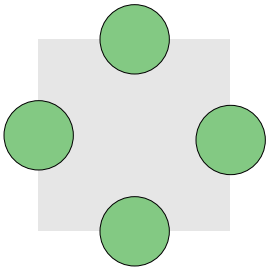
Template *E* (half-size)



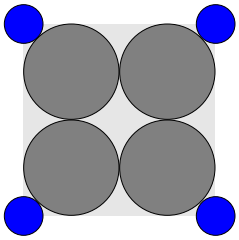
Pattern (actual size)



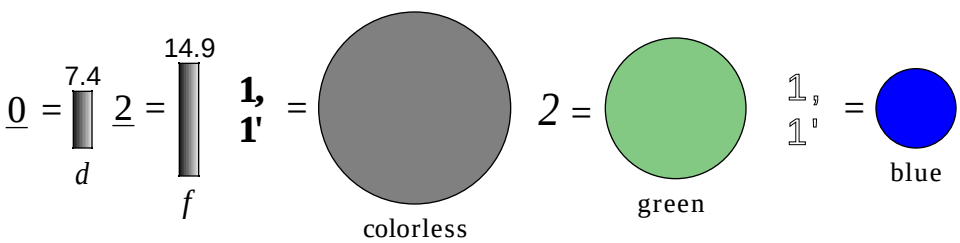
Unit cell layers (half-size)



layer 2, *z* = 1/2



layer 1, *z* = 0



Body-Centered Cubic

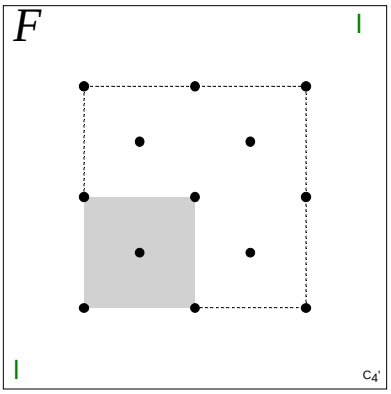
To build a unit cell:

- Position the | on template *F* in the same corner as the matching | on the base and align holes.
- Insert rods in all 5 holes in the shaded region.
- Build each layer in numerical order, **1** through **2**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

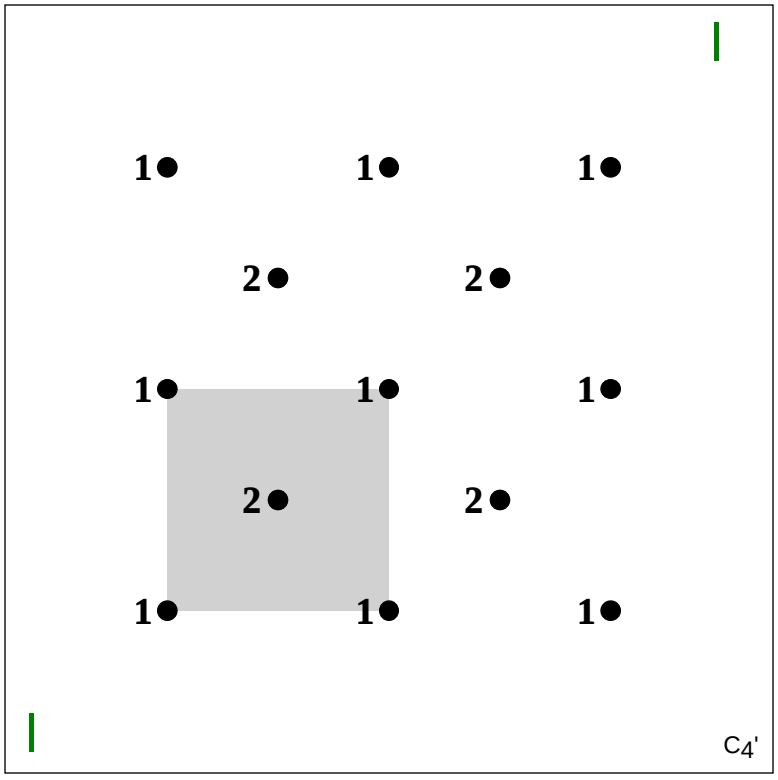
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

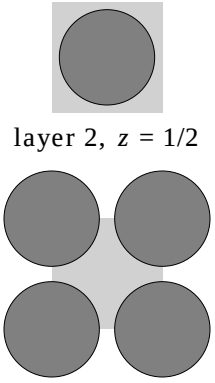
Template *F* (half-size)



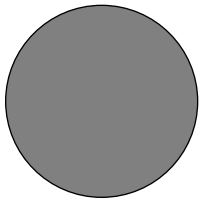
Pattern (actual size)



Unit cell layers (half-size)



1, 2, 1' =



colorless

BiF_3

- This model uses two different colors of the large spheres.

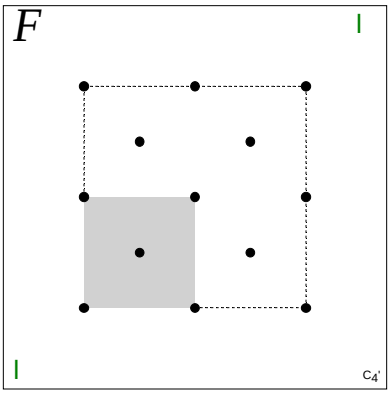
` To build a unit cell:

- Position the | on template *F* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1',** 1').

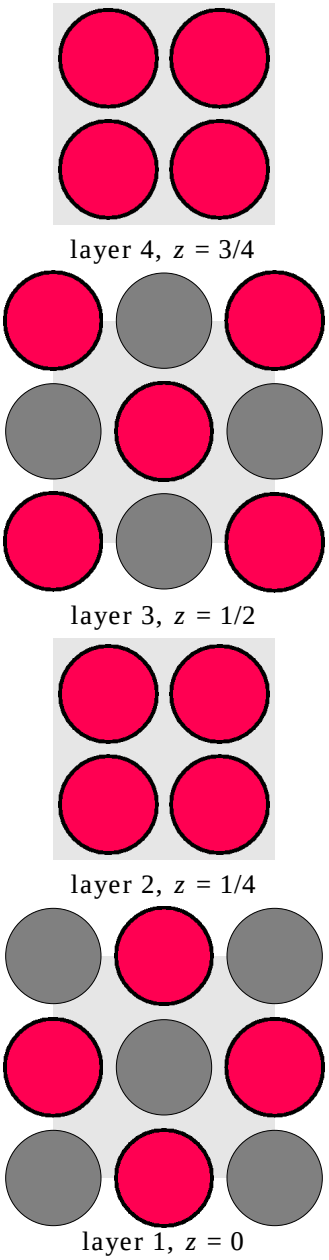
To build more than a unit cell:

- When building the structure higher, repeat the layers in order.

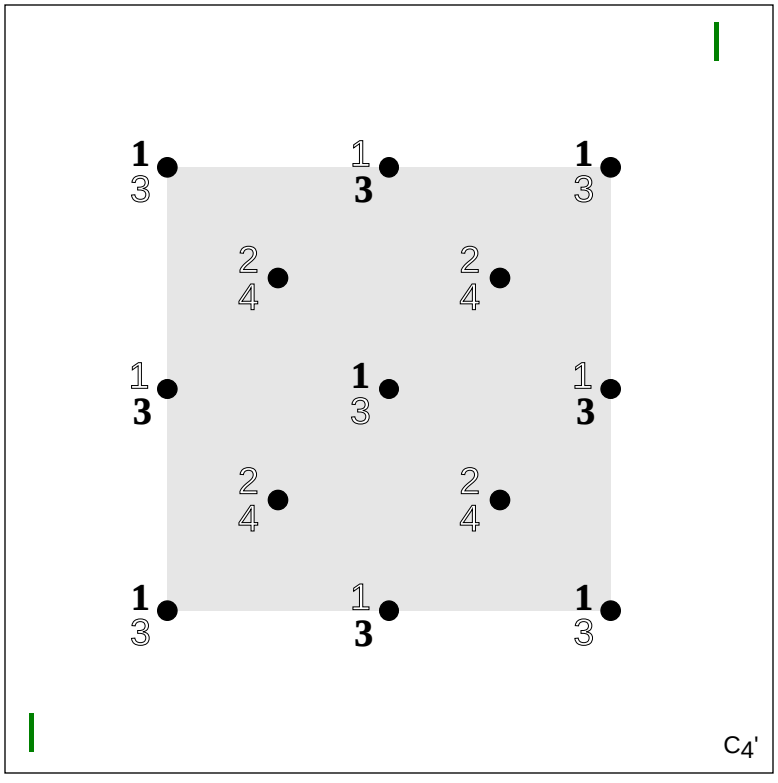
Template *F* (half-size)

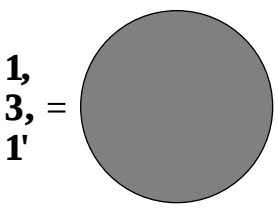


Unit cell layers (half-size)

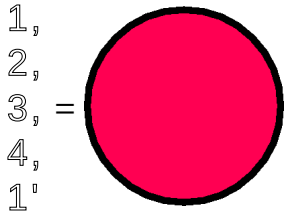


Pattern (actual size)





colorless



colored

Cu_2AlMn

- This model uses three different colors of the large spheres.

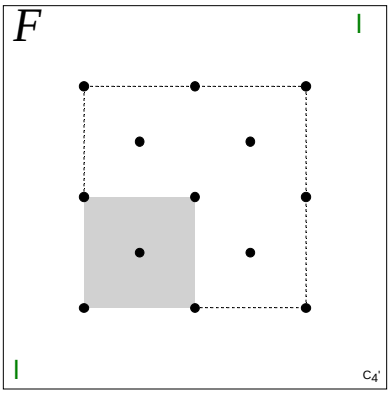
` To build a unit cell:

- Position the | on template *F* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes.
- Build each layer in numerical order, **1** through *4*, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

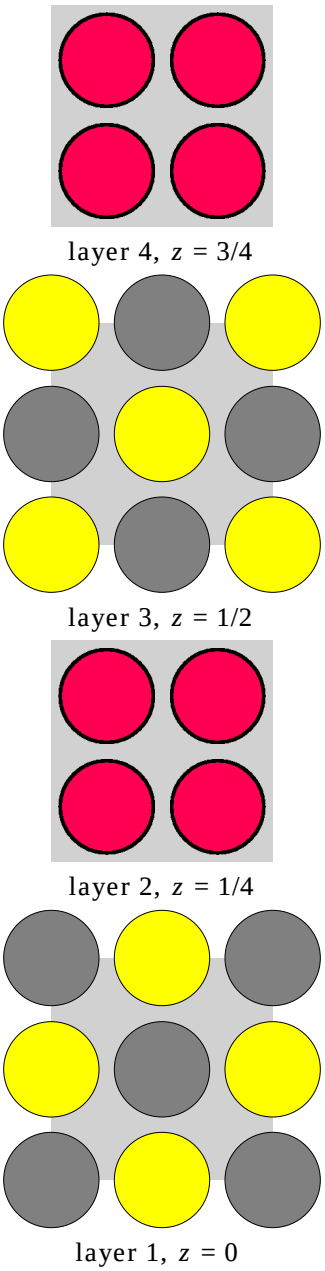
To build more than a unit cell:

- When building the structure higher, repeat the layers in order.

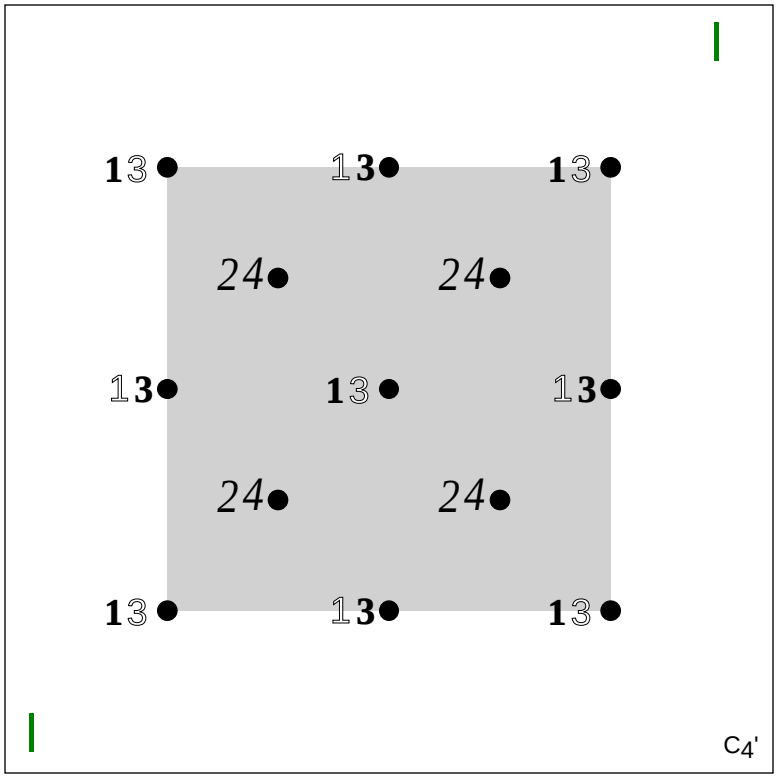
Template *F* (half-size)

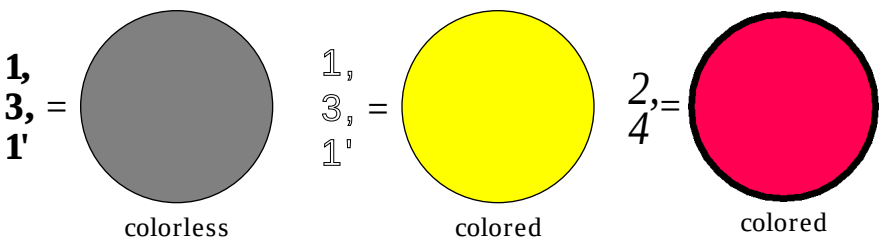


Unit cell layers (half-size)



Pattern (actual size)





NaTl

- This model uses two different colors of the large spheres.

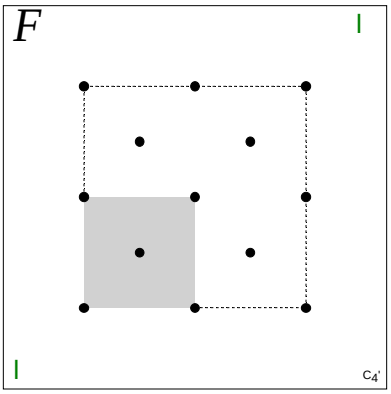
To build a unit cell:

- Position the | on template *F* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1',** 1').

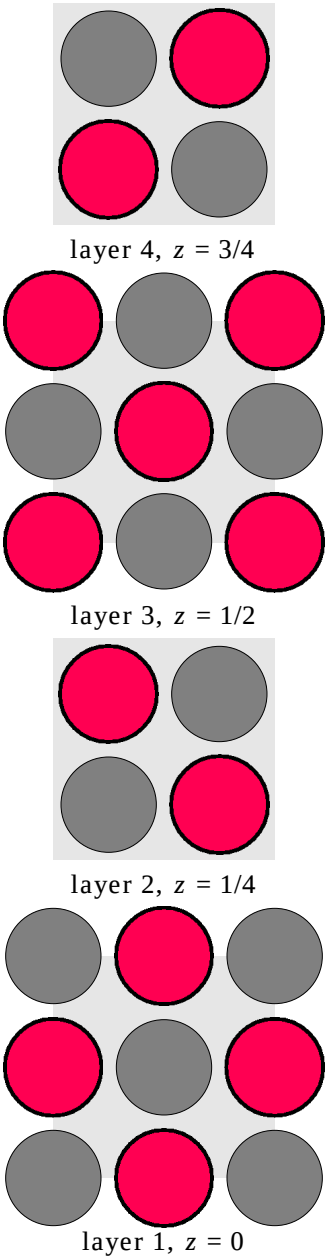
To build more than a unit cell:

- When building the structure higher, repeat the layers in order.

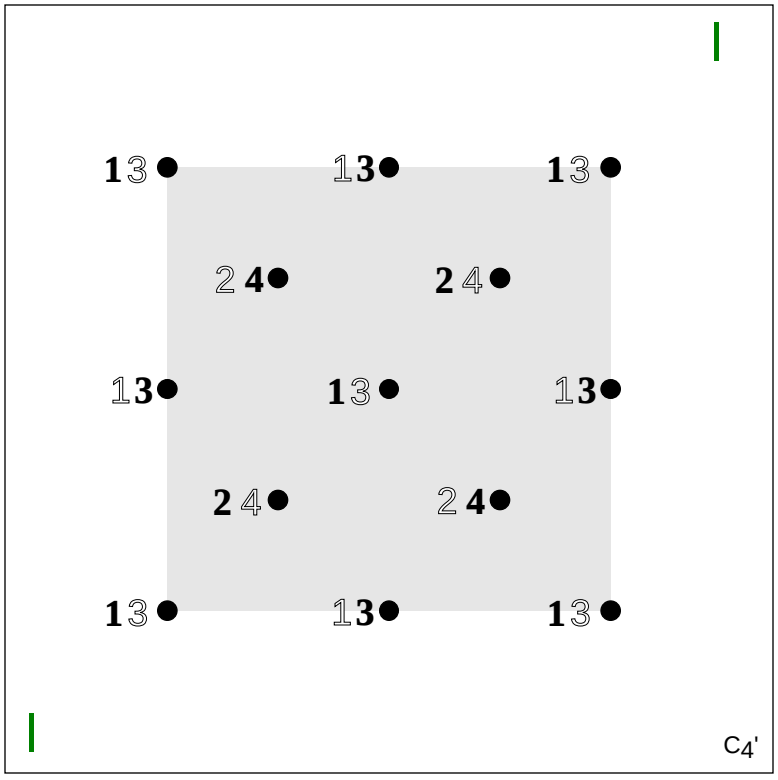
Template *F* (half-size)

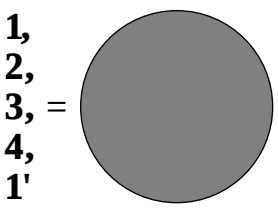


Unit cell layers (half-size)

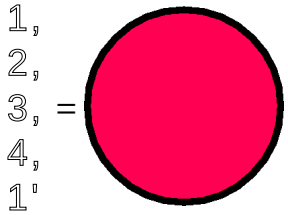


Pattern (actual size)





colorless



colored

NaTl (alternate)

- Instead of using differently colored large spheres, this model uses different size spheres to represent Na and Tl.

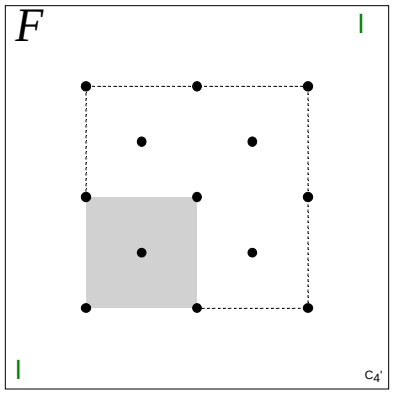
To build a unit cell:

- Position the | on template *F* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes.
- Build each layer in numerical order, **1** through 5, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1',** 1').

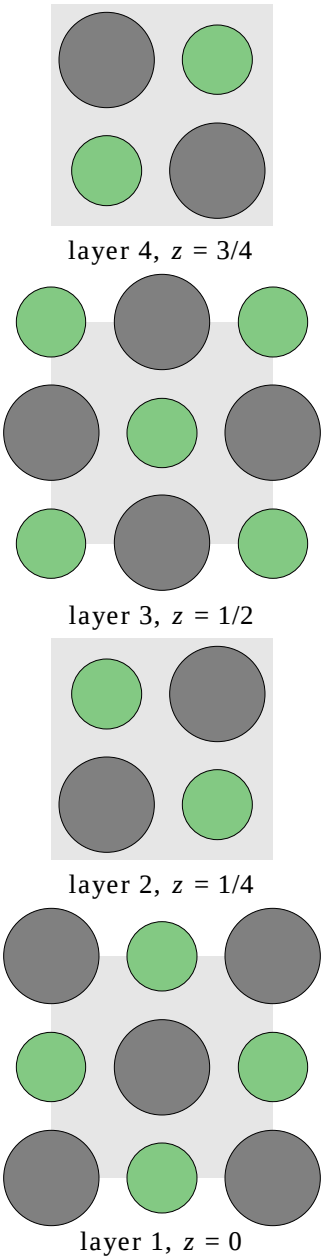
To build more than a unit cell:

- When building the structure higher, repeat the layers in order.

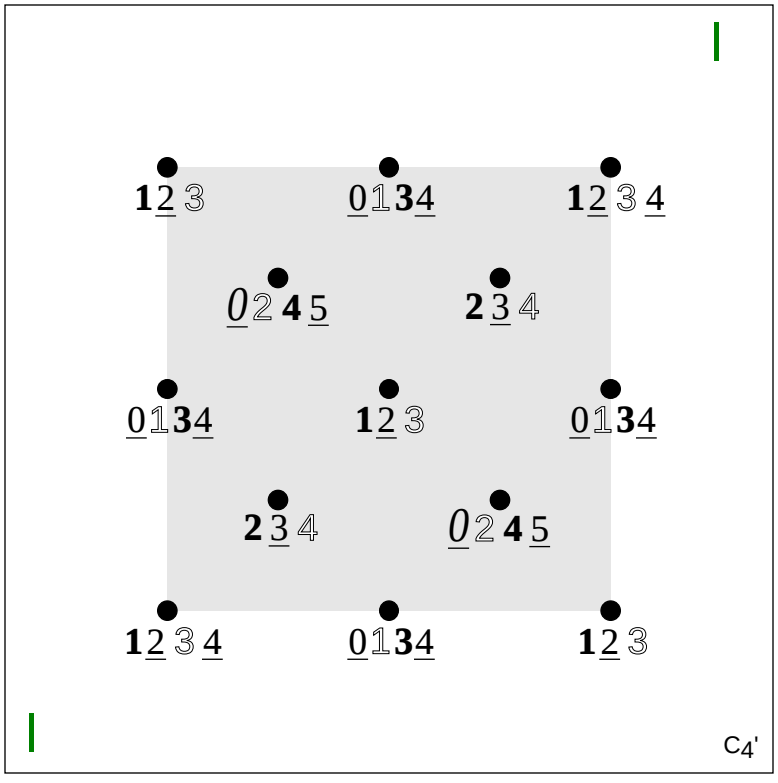
Template *F* (half-size)

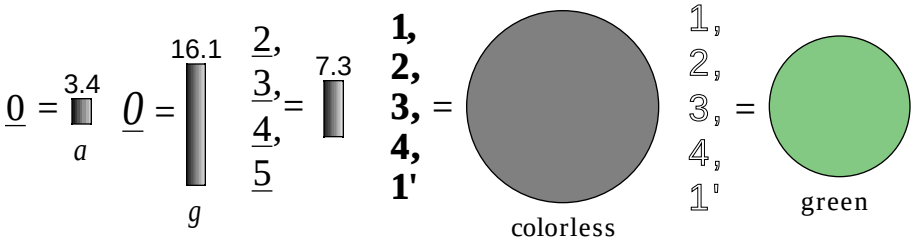


Unit cell layers (half-size)



Pattern (actual size)



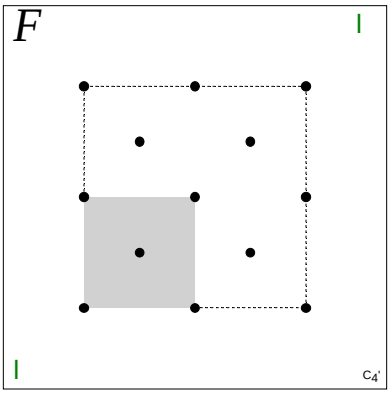


Diamond

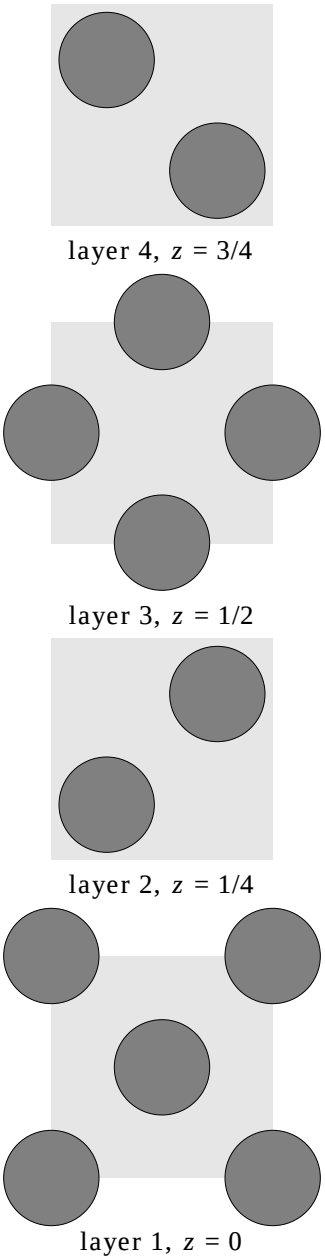
To build a unit cell:

- Position the | on template *F* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

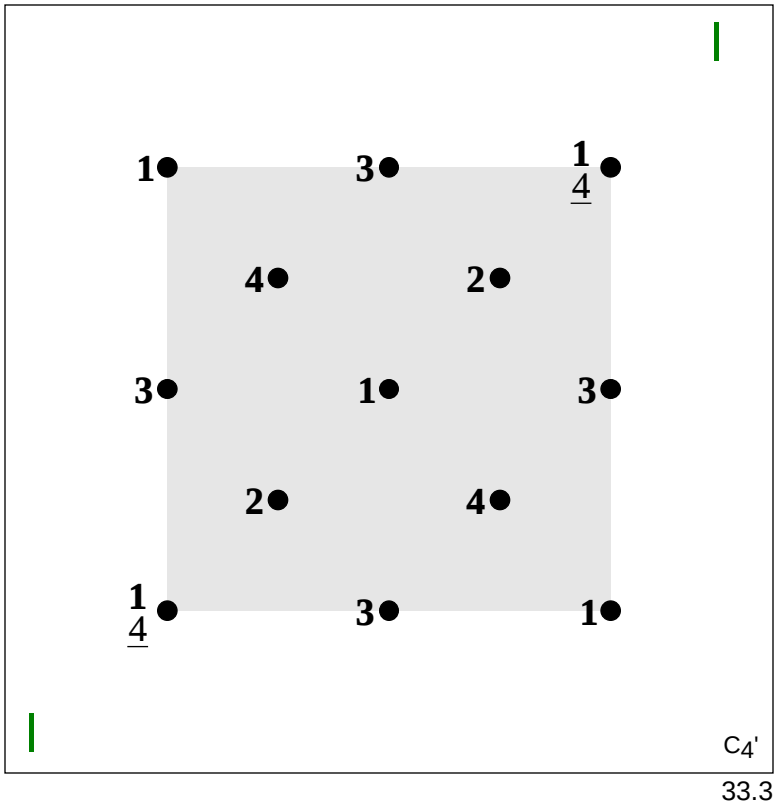
Template *F* (half-size)



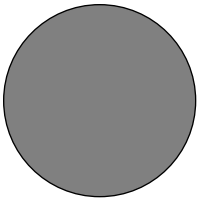
Unit cell layers (half-size)



Pattern (actual size)



1, 2, 3, 4, 1' =



colorless

4 =

Hexagonal Close-Packing

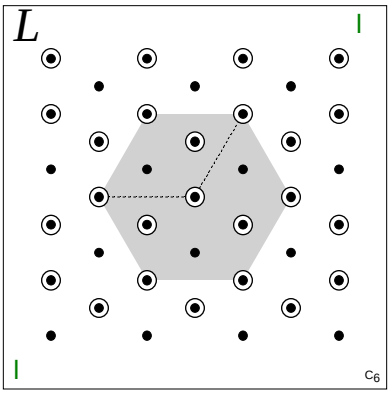
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in the 10 circled holes in the shaded region.
- Build each layer in numerical order, **1** through **2**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

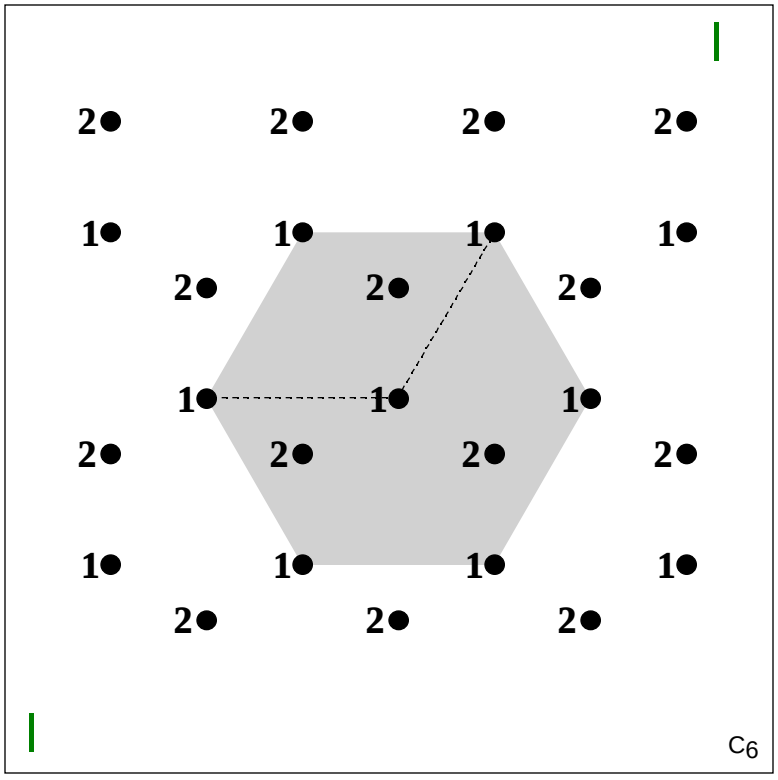
To build more than a hexagonal section:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

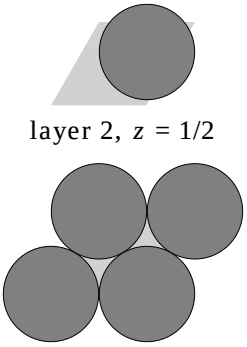
Template *L* (half-size)



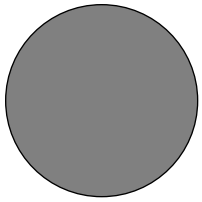
Pattern (actual size)



Unit cell layers (half-size)



1, 2, 1' =



colorless

Cubic Close-Packing

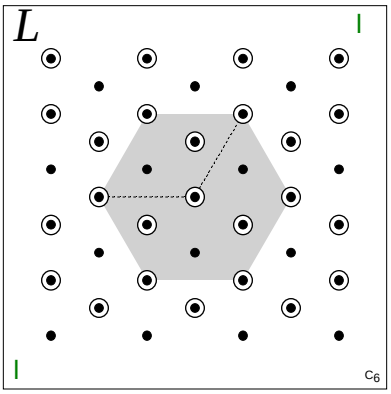
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

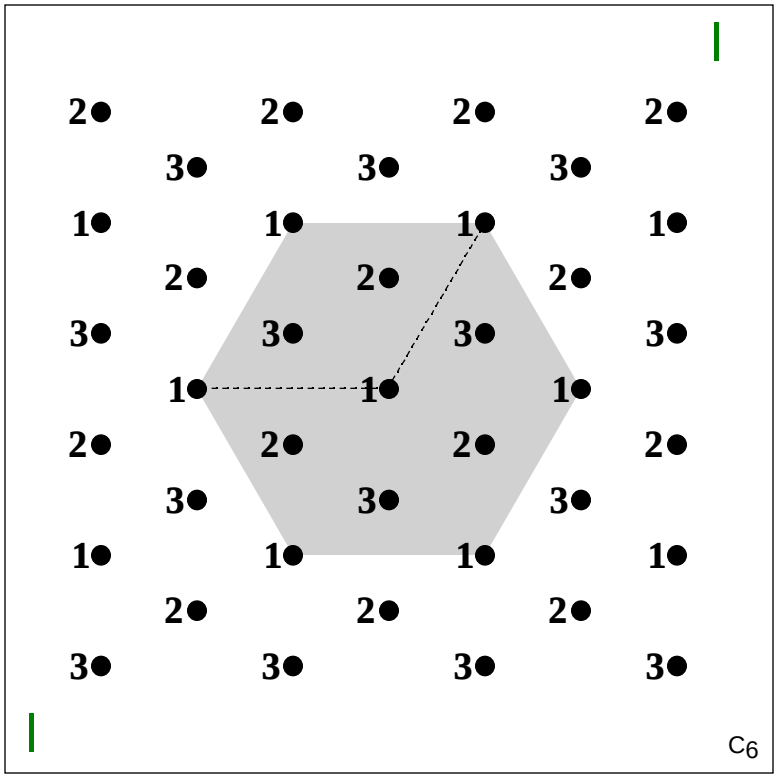
To build more than a hexagonal section:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

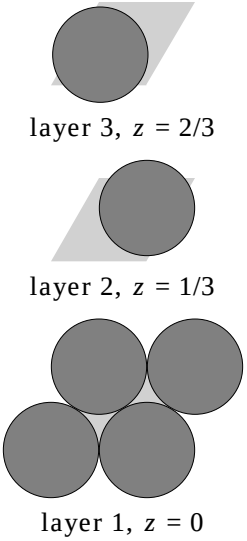
Template *L* (half-size)



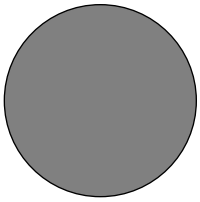
Pattern (actual size)



Unit cell layers (half-size)



1, 2, 3, 1' =



colorless

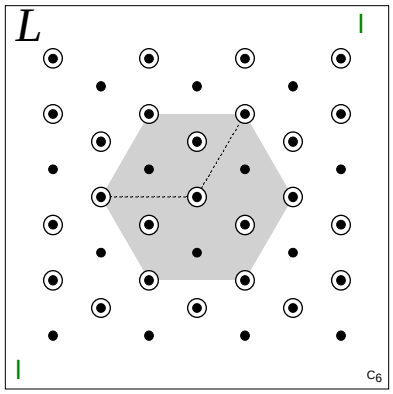
Cubic Close-Packing (with body diagonal cube)

- This model uses two different colors of the large spheres to highlight the cube in cubic close-packing.

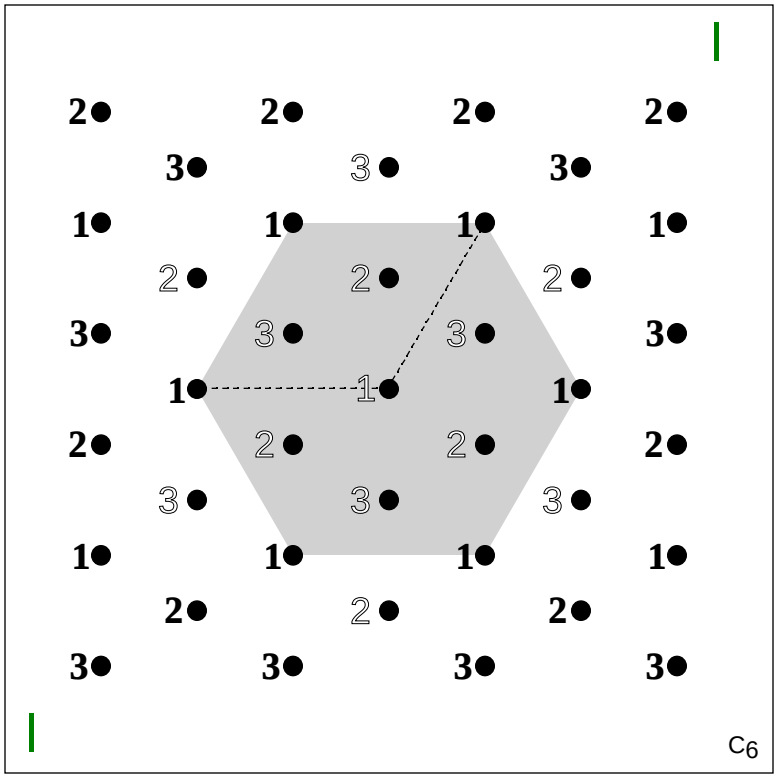
` To build more than a unit cell:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 39 holes.
- Build each layer in numerical order, **1** through 3, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**, 1').

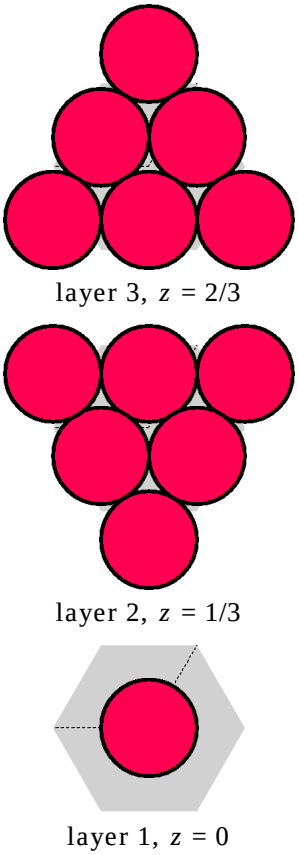
Template *L* (half-size)

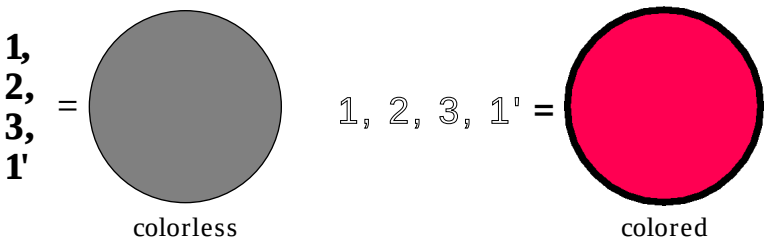


Pattern (actual size)



Unit cell layers (half-size)





Face-Centered Cubic

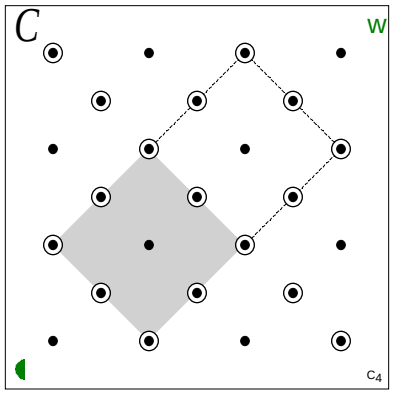
To build a unit cell:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, **1** through **2**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

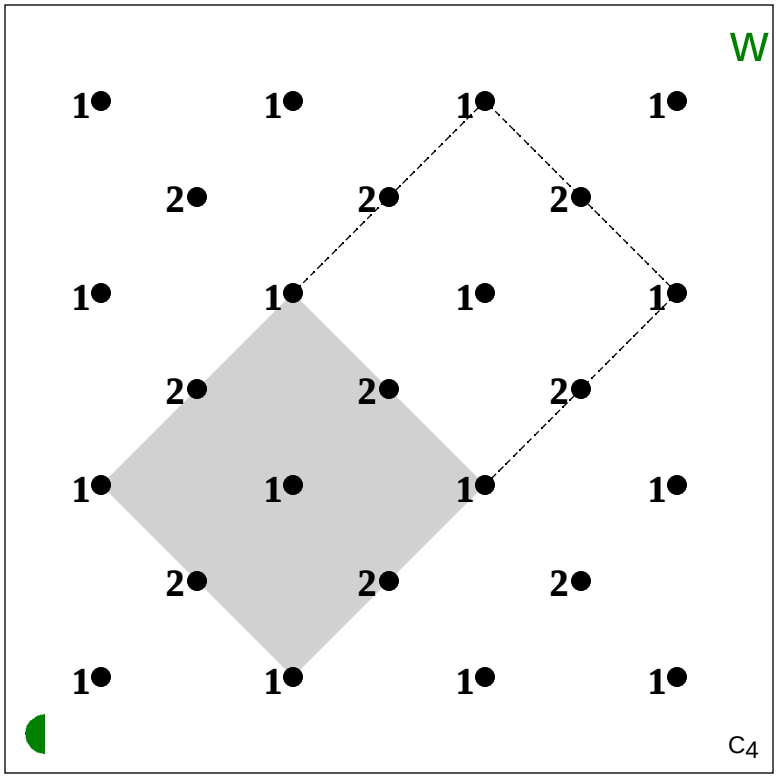
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

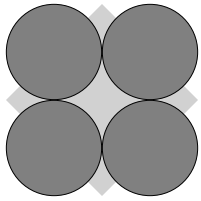
Template *C* (half-size)



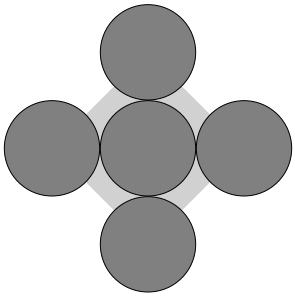
Pattern (actual size)



Unit cell layers (half-size)

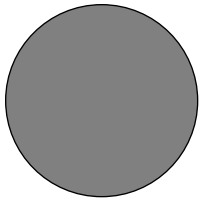


layer 2, *z* = 1/2



layer 1, *z* = 0

1, 2, 1' =



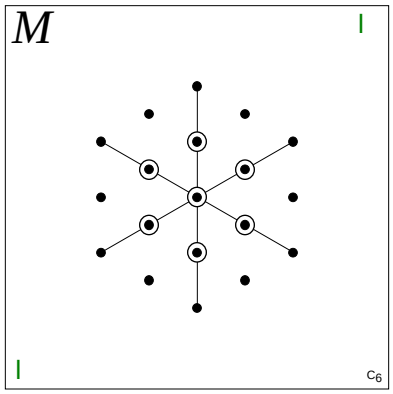
colorless

Face-Centered Cubic (body diagonal)

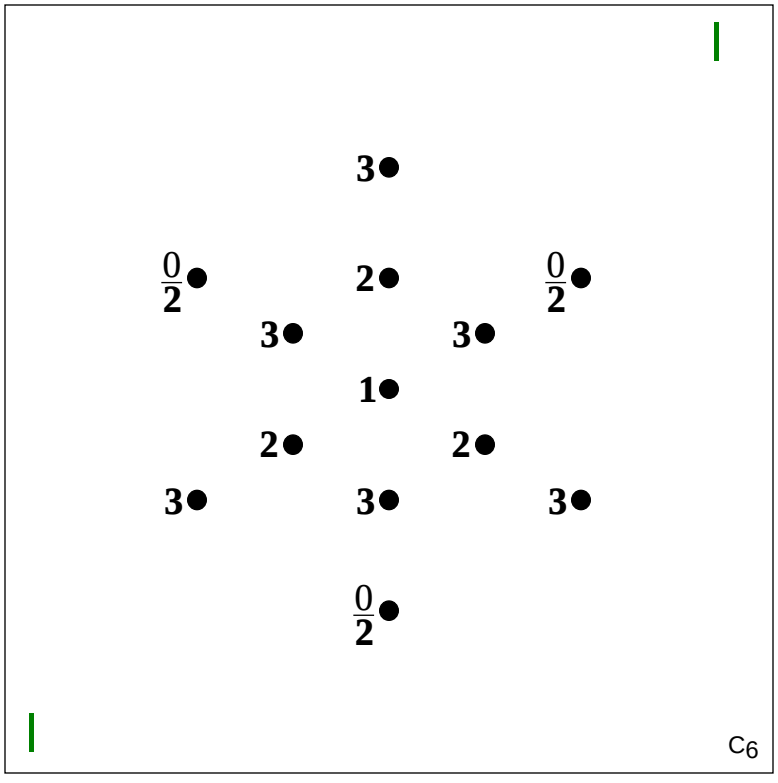
To build a unit cell:

- Position the | on template *M* in the same corner as the matching | on the base and align holes.
- Insert rods in the 13 line-connected holes.
- Build each layer in numerical order, 0 through **3**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

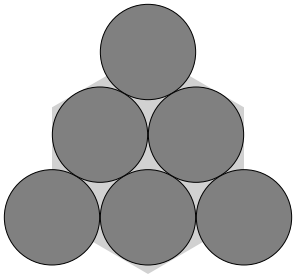
Template *M* (half-size)



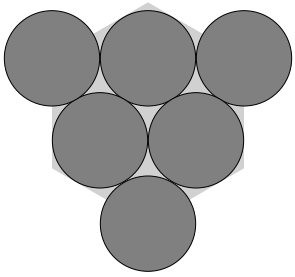
Pattern (actual size)



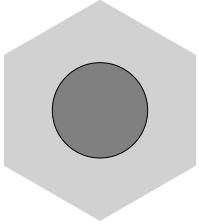
Unit cell layers (half-size)



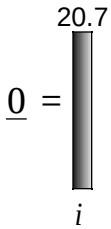
layer 3, z = 2/3

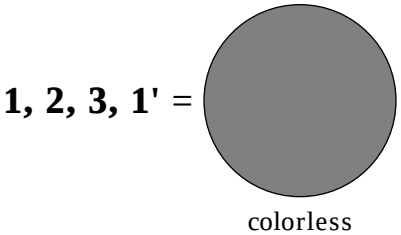


layer 2, z = 1/3



layer 1, z = 0





CuAu

- This model uses two different colors of the large spheres.

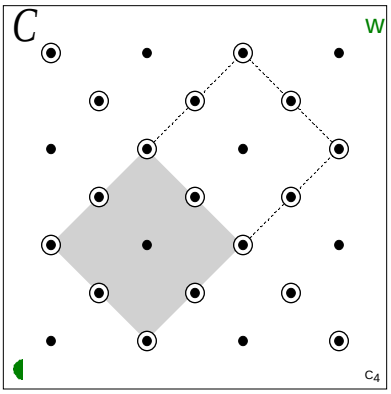
To build a unit cell:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

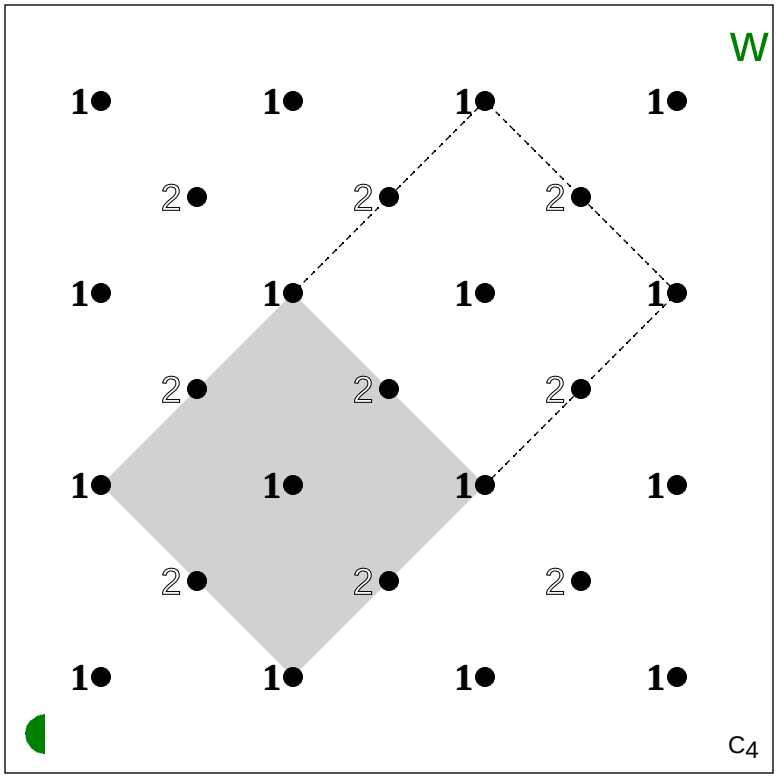
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

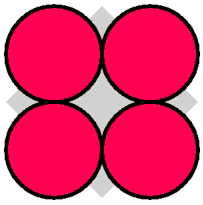
Template *C* (half-size)



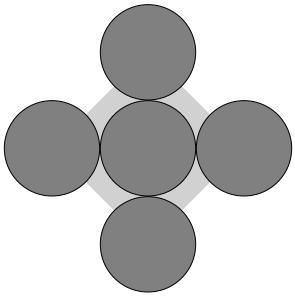
Pattern (actual size)



Unit cell layers (half-size)

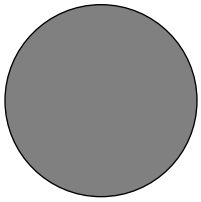


layer 2, z = 1/2



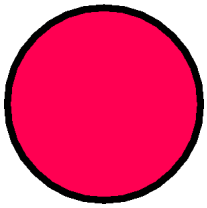
layer 1, z = 0

1, 1' =



colorless

2 =



colored

Cu_3Au

- This model uses two different colors of the large spheres

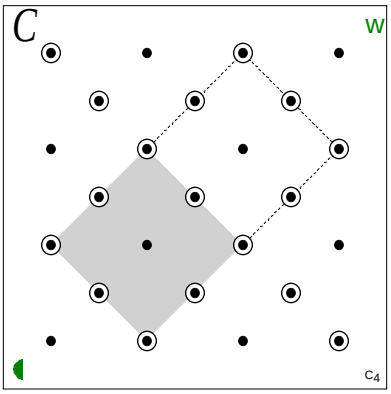
To build a unit cell:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

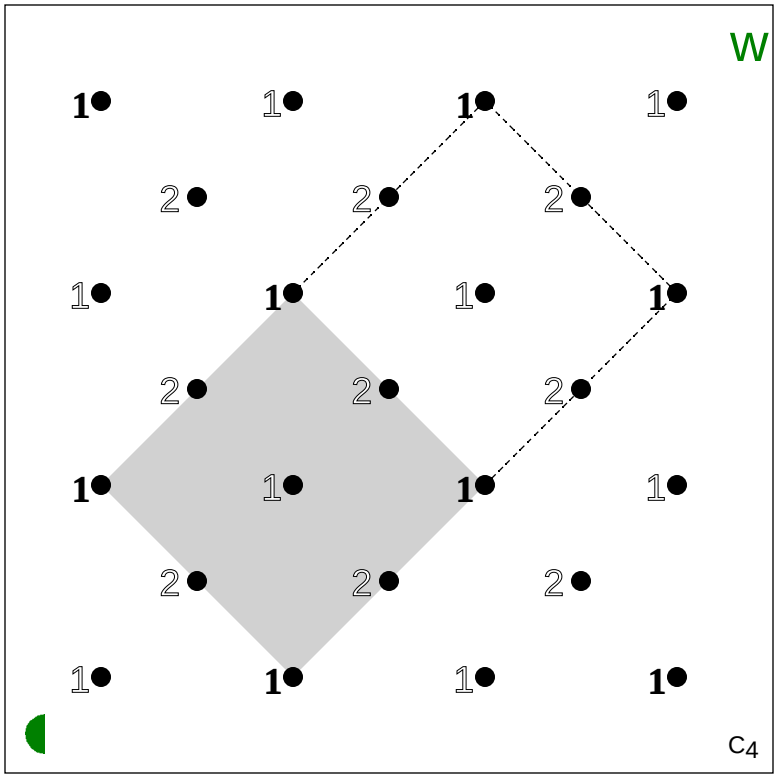
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

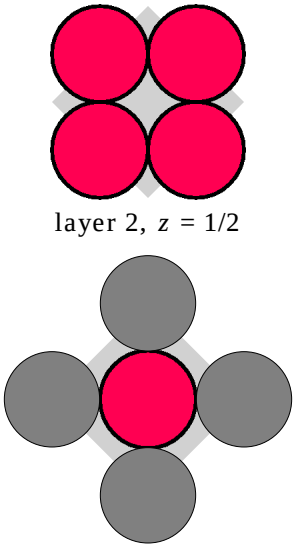
Template *C* (half-size)



Pattern (actual size)



Unit cell layers (half-size)



layer 2, z = 1/2

layer 1, z = 0

1, 1' =

colorless

1, 2, 1' =

colored

NaCl (cubic close-packed)

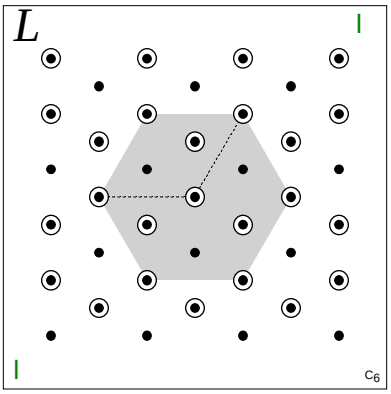
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 6, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

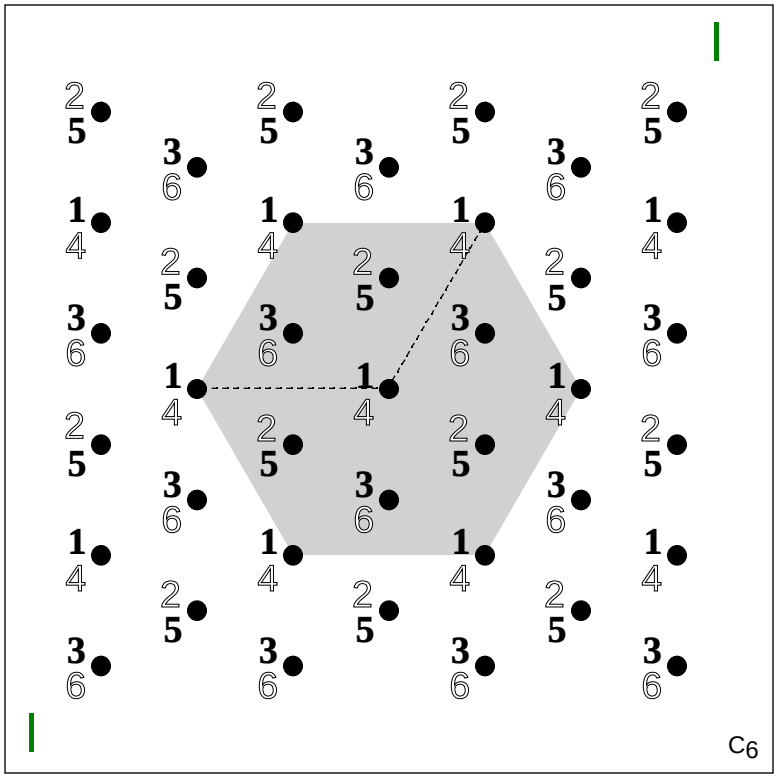
To build more than a hexagonal section:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

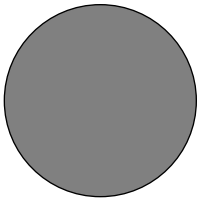
Template *L* (half-size)



Pattern (actual size)



1, 3, 5, 1' =

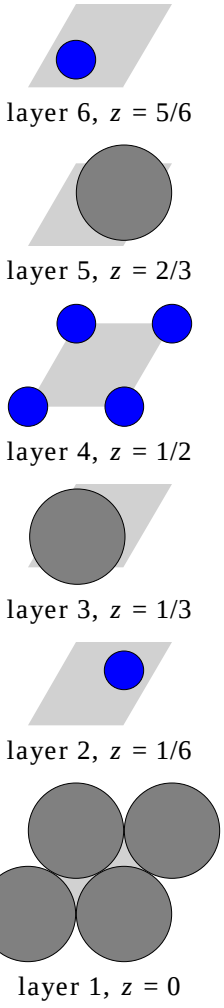


colorless

2, 4, 6 =

blue

Unit cell layers (half-size)

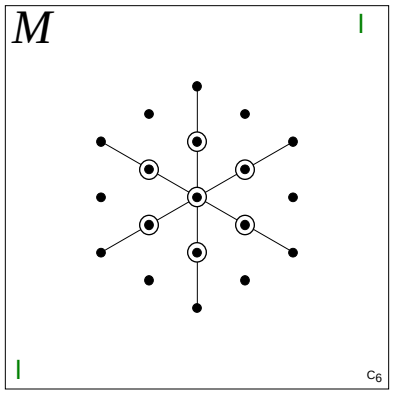


NaCl (body diagonal)

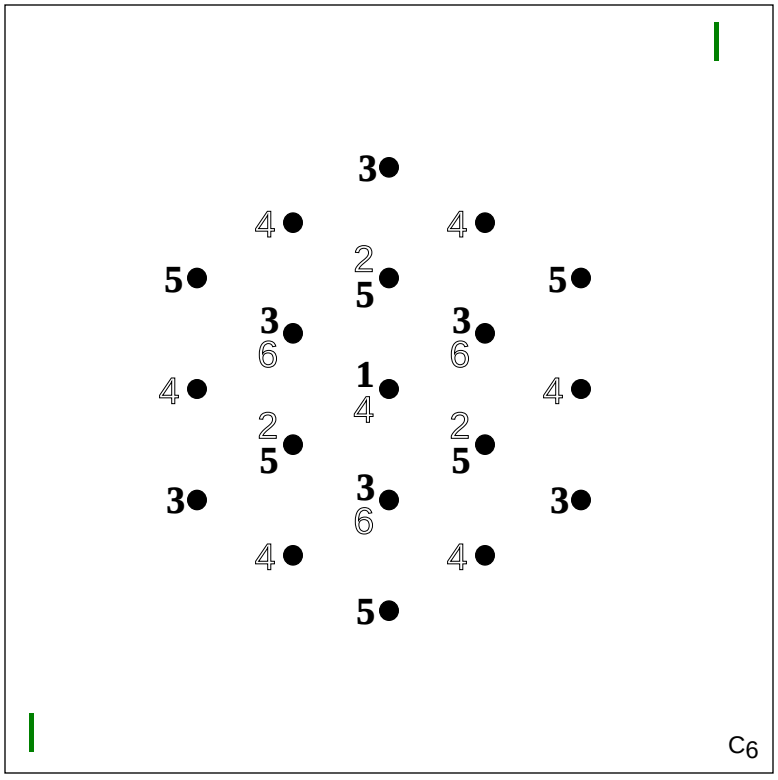
To build a unit cell:

- Position the | on template *M* in the same corner as the matching | on the base and align holes.
- Insert rods in all 19 holes.
- Build each layer in numerical order, **1** through 6, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

Template *M* (half-size)



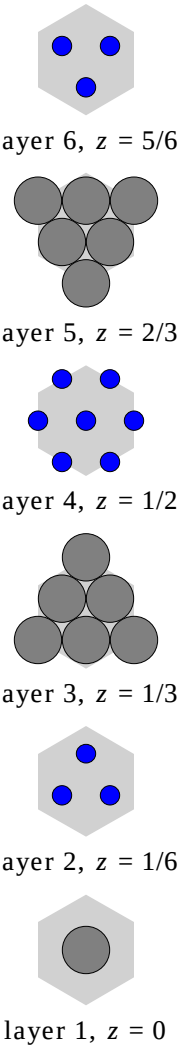
Pattern (actual size)



1, 3, 5, 1' = colorless

2, 4, 6 = blue

Unit cell layers (quarter-size)



NaCl (face-centered cubic)

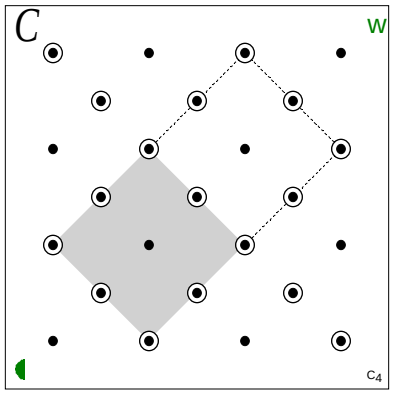
To build a unit cell:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, 0 through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

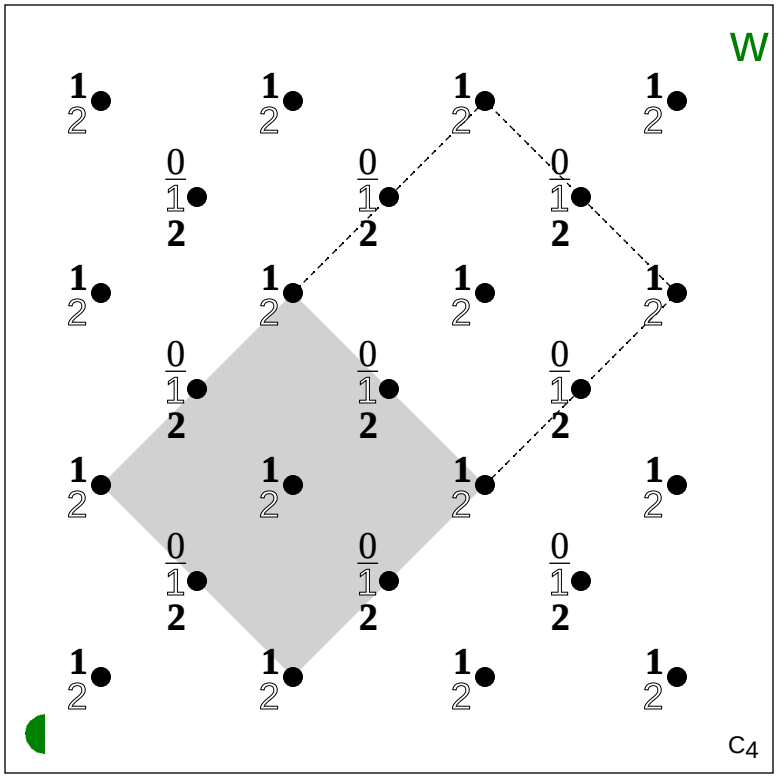
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

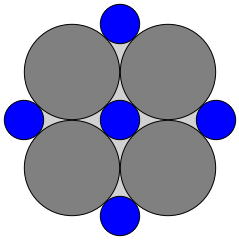
Template *C* (half-size)



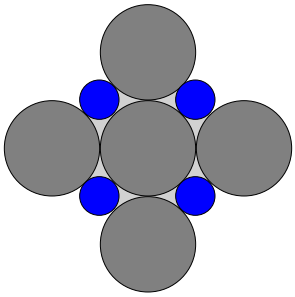
Pattern (actual size)



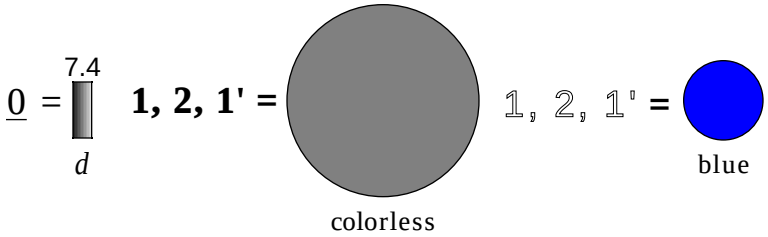
Unit cell layers (half-size)



layer 2, *z* = 1/2



layer 1, *z* = 0



Cadmium Chloride

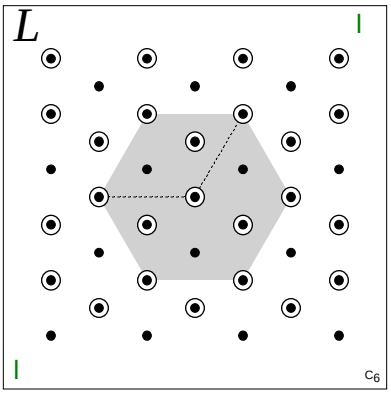
` To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through **9**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

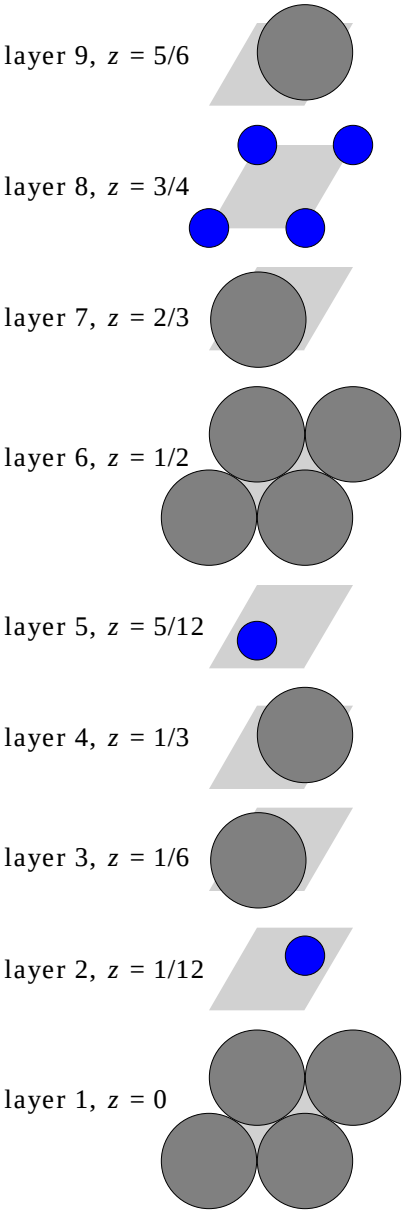
To build more than a hexagonal section:

- Place rods in additional holes before placing spheres. Follow the same directions as above.

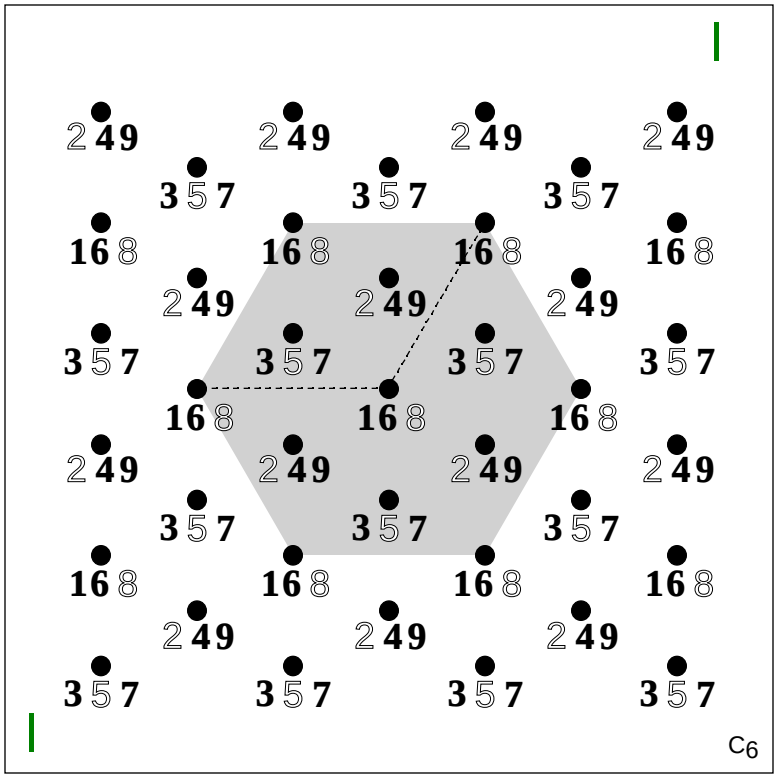
Template *L* (half-size)



Unit cell layers (half-size)



Pattern (actual size)



1, 3, 4, 6, 7, 9, 1' = colorless

2, 5, 8 = blue

Nickel Arsenide

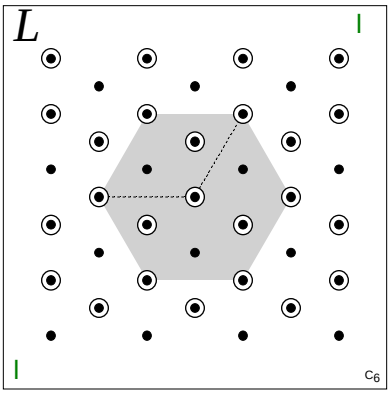
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

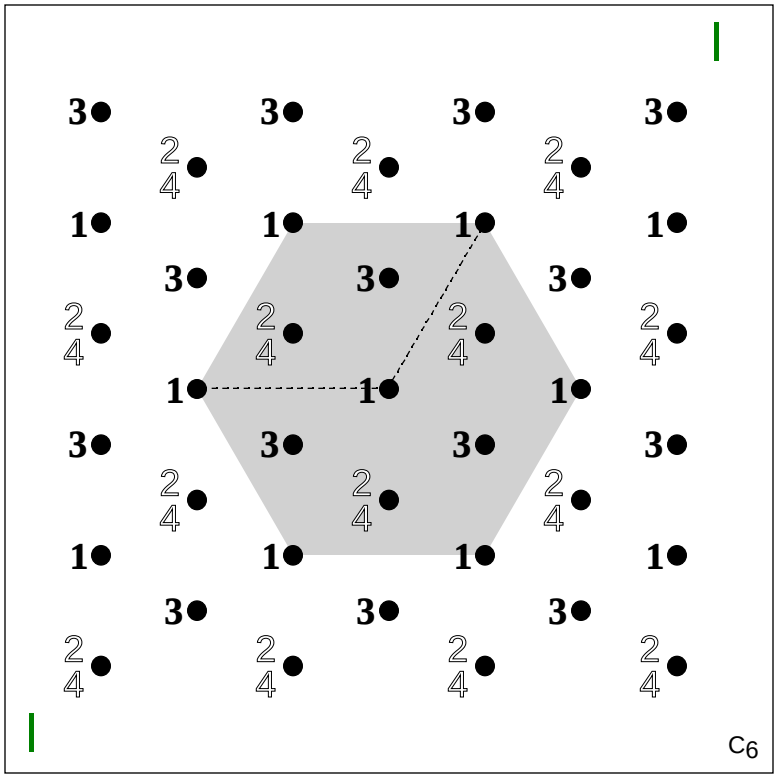
To build more than a hexagonal section:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

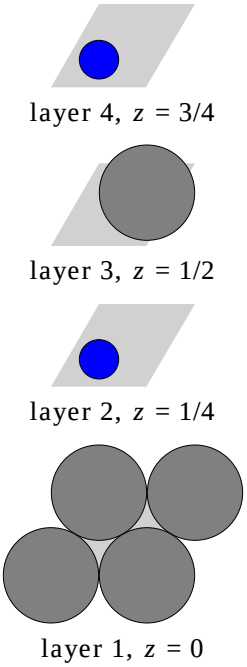
Template *L* (half-size)



Pattern (actual size)



Unit cell layers (half-size)



1, 3, 1' = colorless

2, 4 = blue

Cadmium Iodide

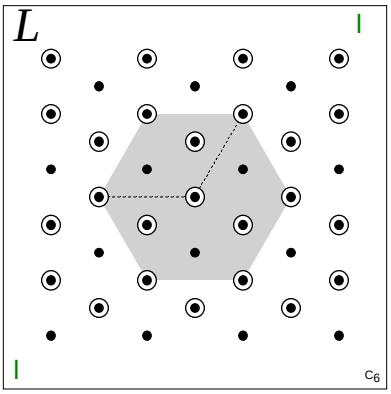
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

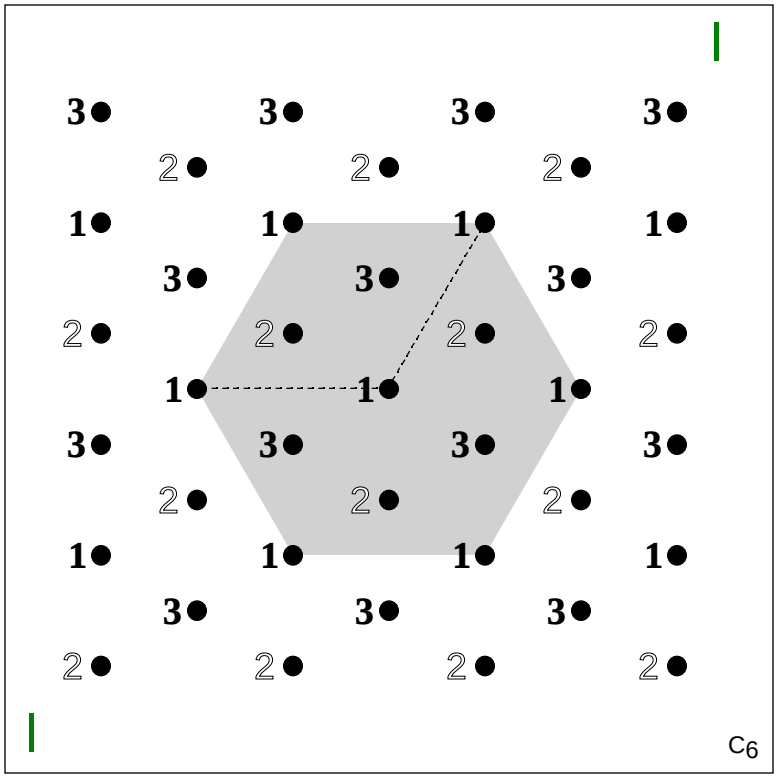
To build more than a hexagonal section:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

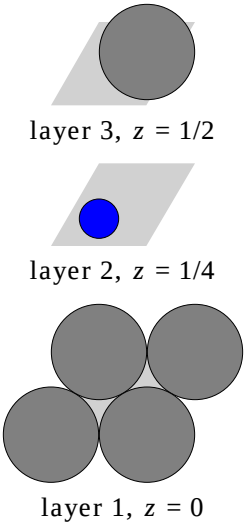
Template *L* (half-size)



Pattern (actual size)



Unit cell layers (half-size)



1, 3, 1' = colorless

2 = blue

Corundum (α-alumina)

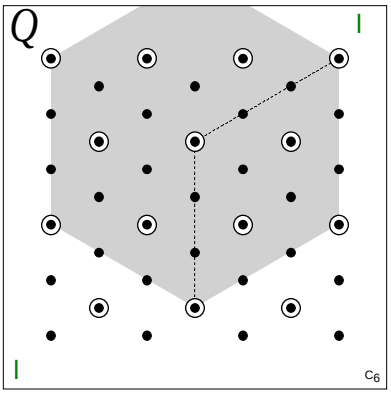
` To build a unit cell:

- Position the | on template *Q* in the same corner as the matching | on the base and align holes.
- Insert rods in the 16 holes in the parallelogram region.
- Build each layer in numerical order, **1** through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

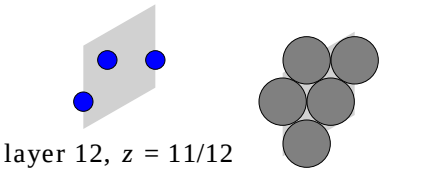
To build more than a hexagonal unit:

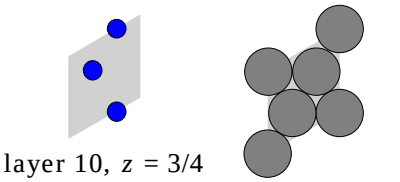
- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

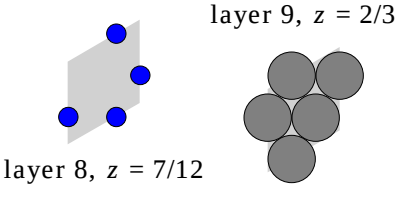
Template *Q* (half-size)

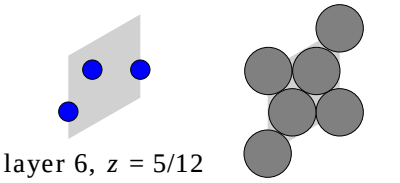


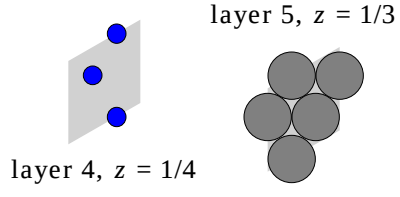
Unit cell layers (quarter-size)

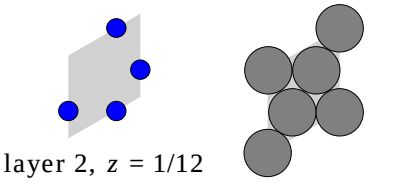




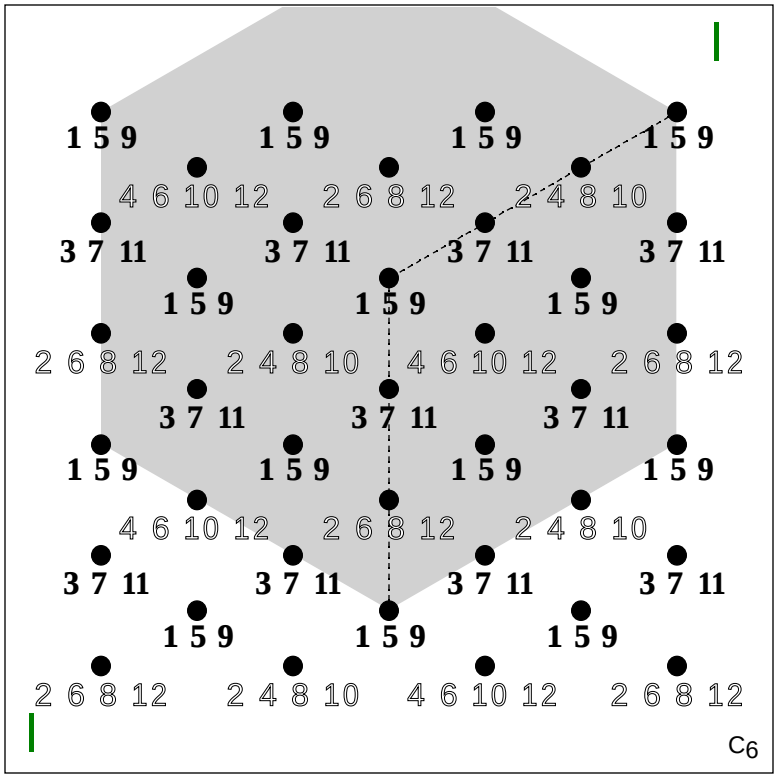








Pattern (actual size)



1, 3, 5, 7, 9, 11, 1' = colorless

2, 4, 6, 8, 10, 12 = blue

K_2PtCl_6

- This model uses two different colors of the large spheres.

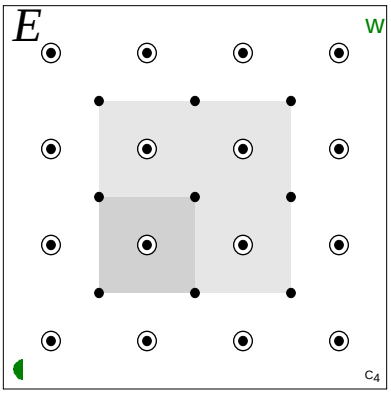
To build a unit cell:

- Position the w on template *E* in the same corner as the matching w on the base and align holes.
- Insert rods in all 13 holes in entire shaded region.
- Build each layer in numerical order, 0 through *4*, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

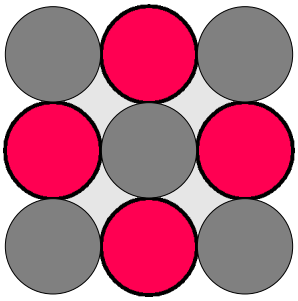
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

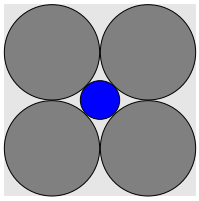
Template *E* (half-size)



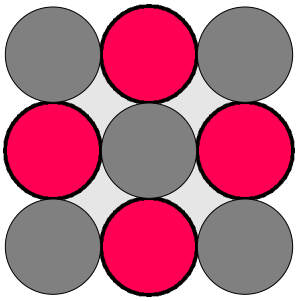
Unit cell layers (half-size)



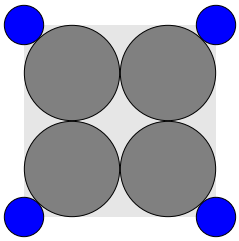
layer 4, *z* = 3/4



layer 3, *z* = 1/2

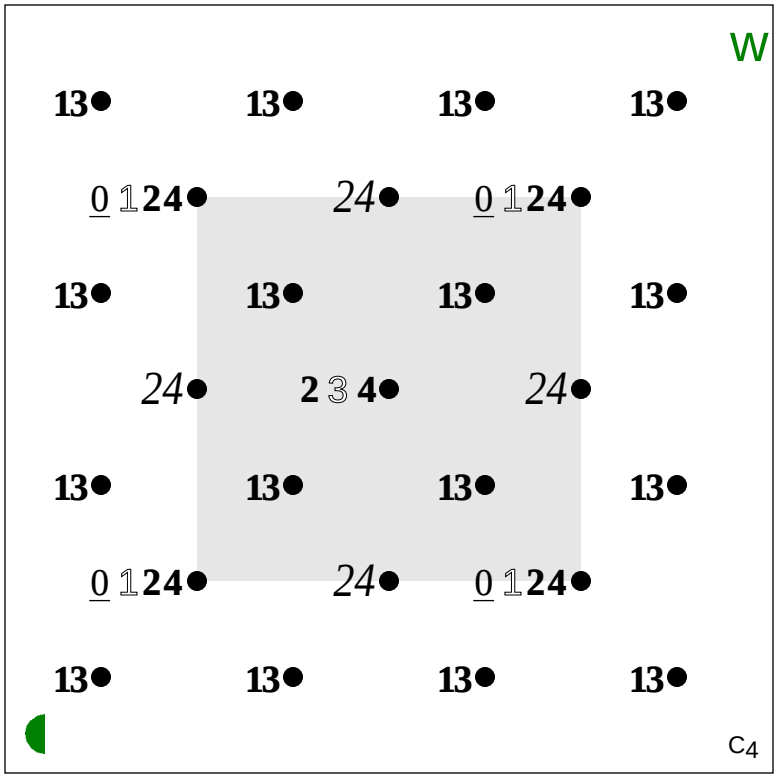


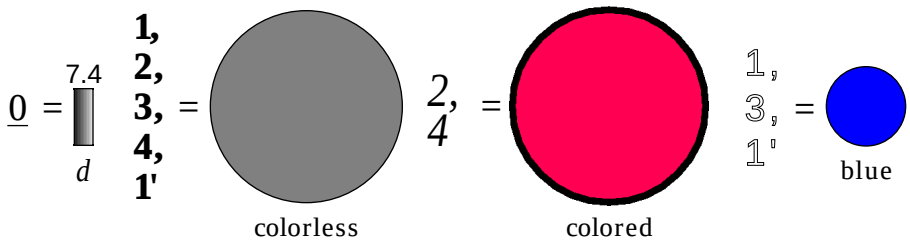
layer 2, *z* = 1/4



layer 1, *z* = 0

Pattern (actual size)





K_2PtCl_6 (alternate)

- Instead of using differently colored large spheres, this model uses the smaller green sphere to represent K.

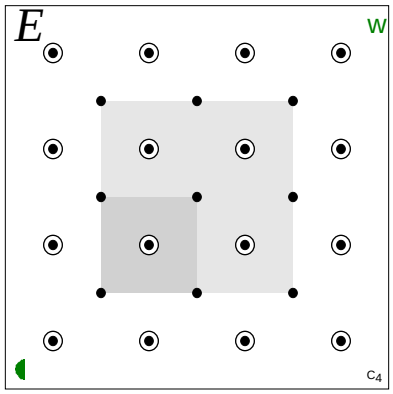
To build a unit cell:

- Position the won template *E* in the same corner as the matching won the base and align holes.
- Insert rods in all 13 holes in the entire shaded region.
- Build each layer in numerical order, 0 through 5, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

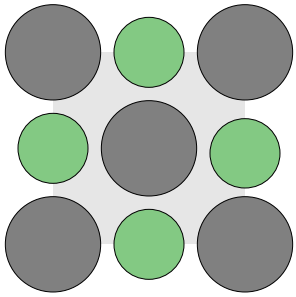
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

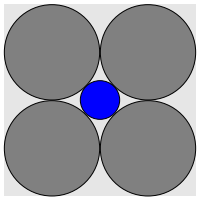
Template *E* (half-size)



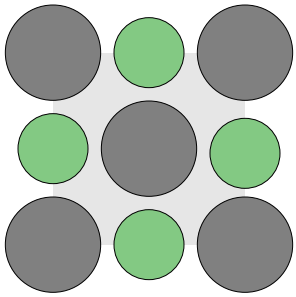
Unit cell layers (half-size)



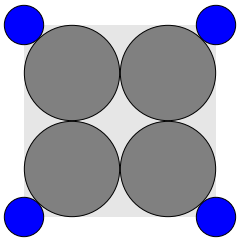
layer 4, *z* = 3/4



layer 3, *z* = 1/2

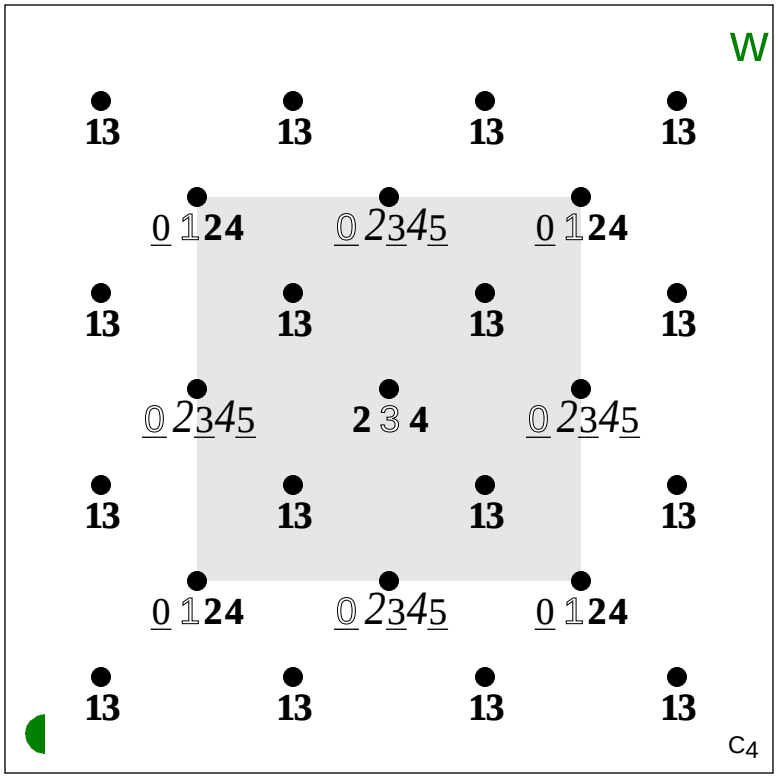


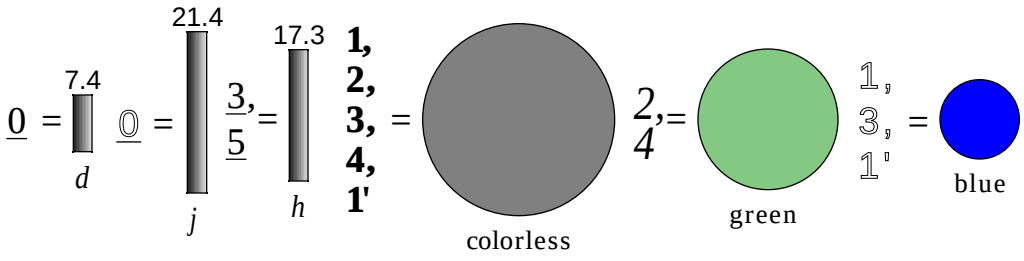
layer 2, *z* = 1/4



layer 1, *z* = 0

Pattern (actual size)





Perovskite, $CaTiO_3$

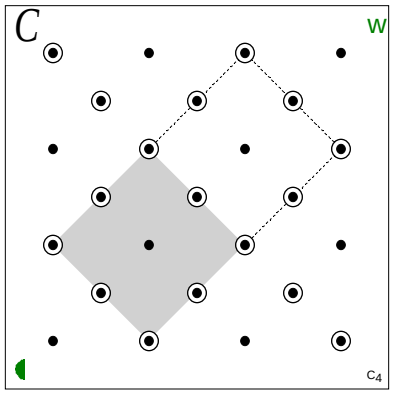
To build a unit cell:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, 0 through *2*, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

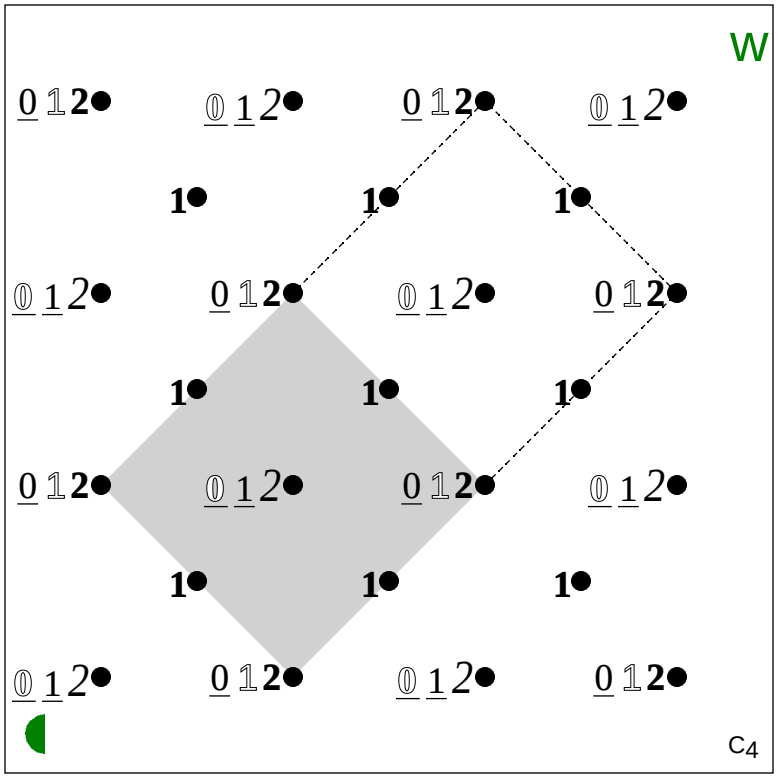
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

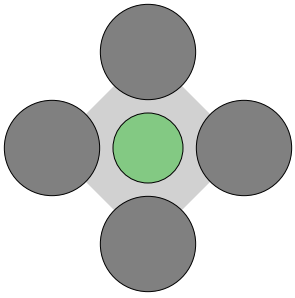
Template *C* (half-size)



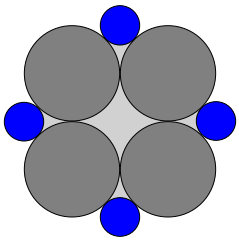
Pattern (actual size)



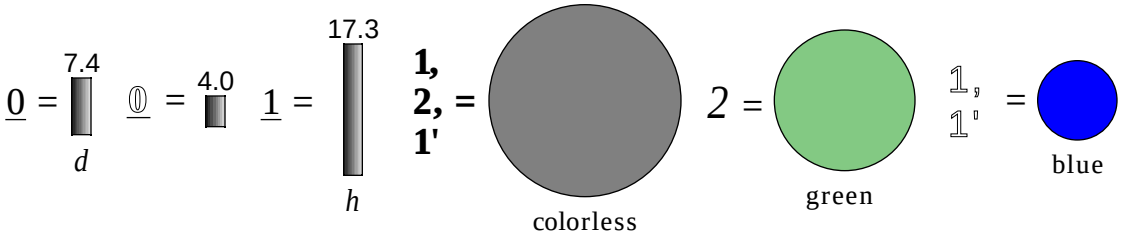
Unit cell layers (half-size)



layer 2, *z* = 1/2



layer 1, *z* = 0



Perovskite, $CaTiO_3$ (alternate)

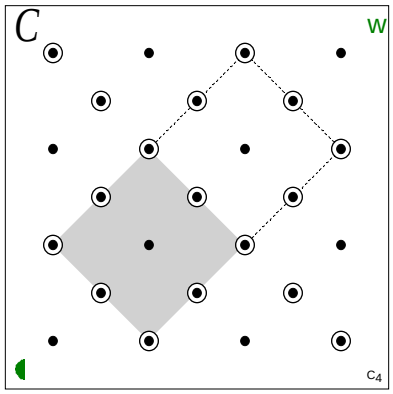
To build a unit cell:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, 0 through *2*, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

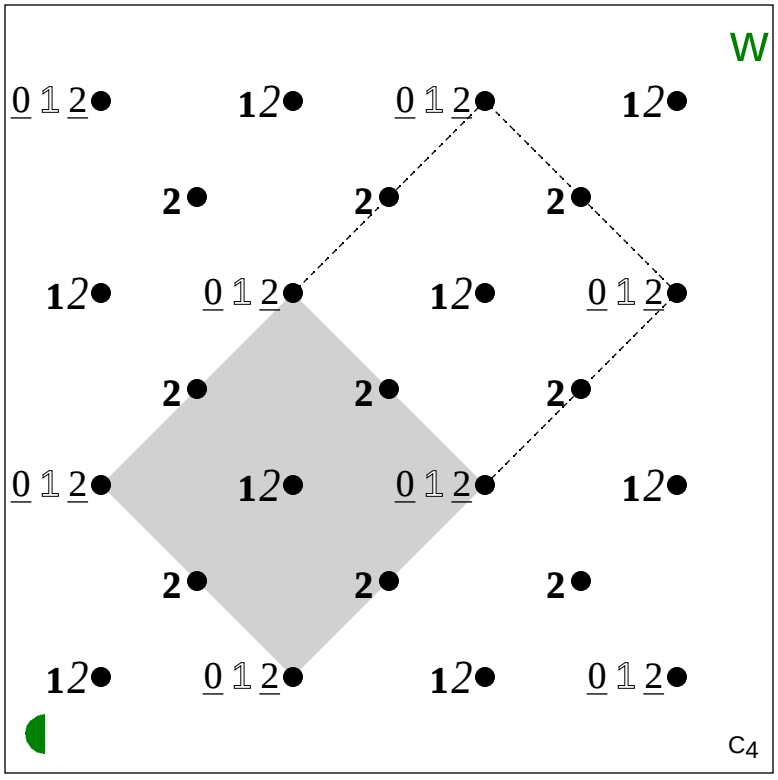
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

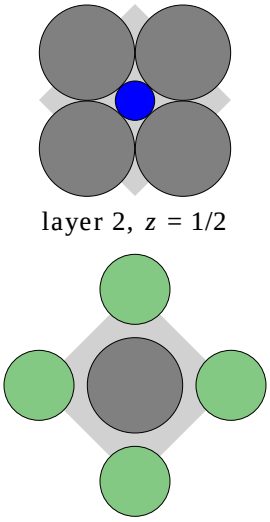
Template *C* (half-size)

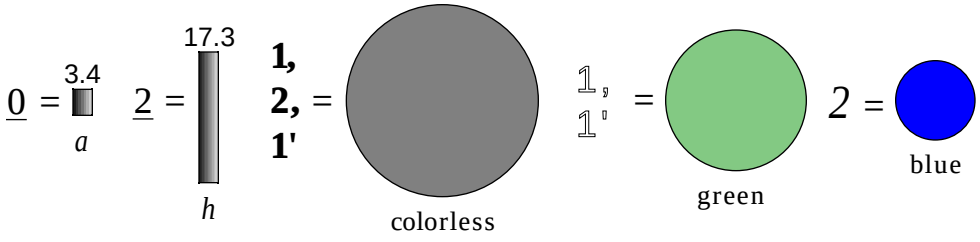


Pattern (actual size)



Unit cell layers (half-size)





ReO_3

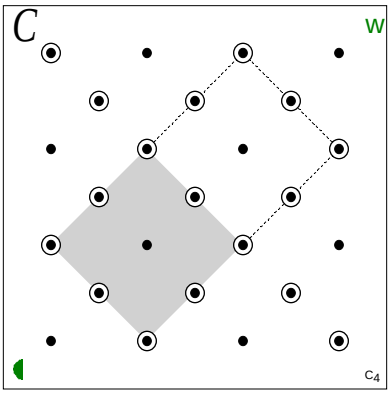
To build a unit cell:

- Position the won template *C* in the same corner as the matching won on the base and align holes.
- Insert rods in the 8 circled holes in the shaded region.
- Build each layer in numerical order, 0 through **2**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

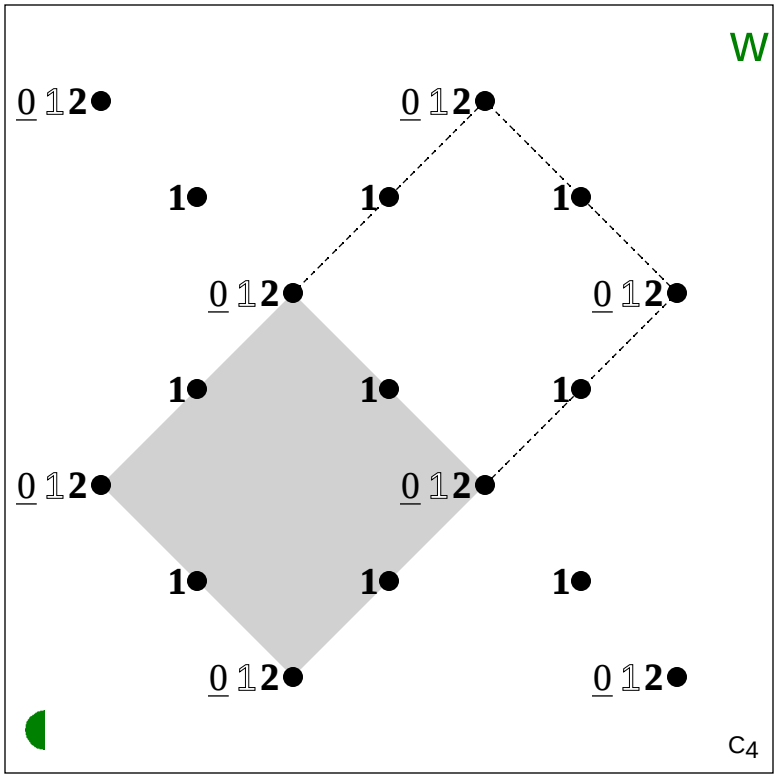
To build more than a unit cell:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

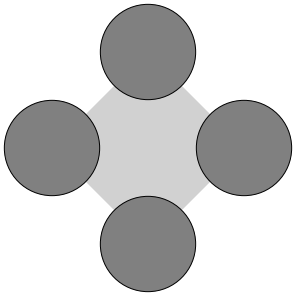
Template *C* (half-size)



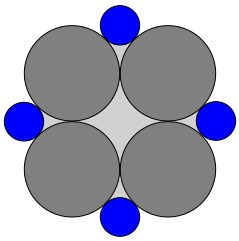
Pattern (actual size)



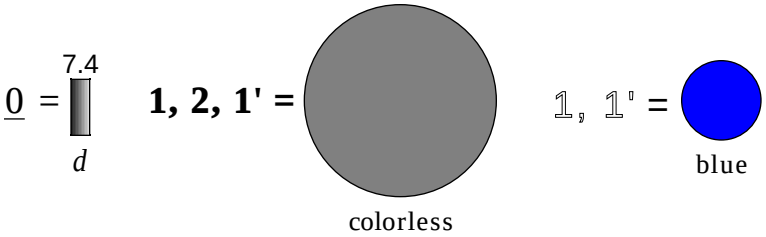
Unit cell layers (half-size)



layer 2, z = 1/2



layer 1, z = 0



ReO_3 (alternate)

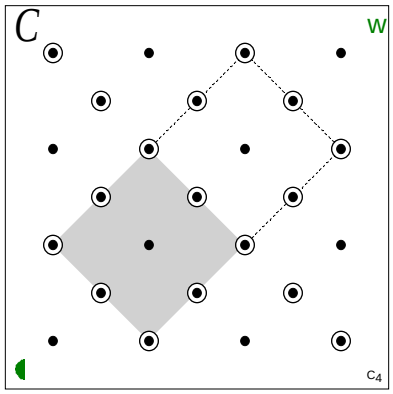
To build a unit cell:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in the 8 circled holes in the shaded region.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

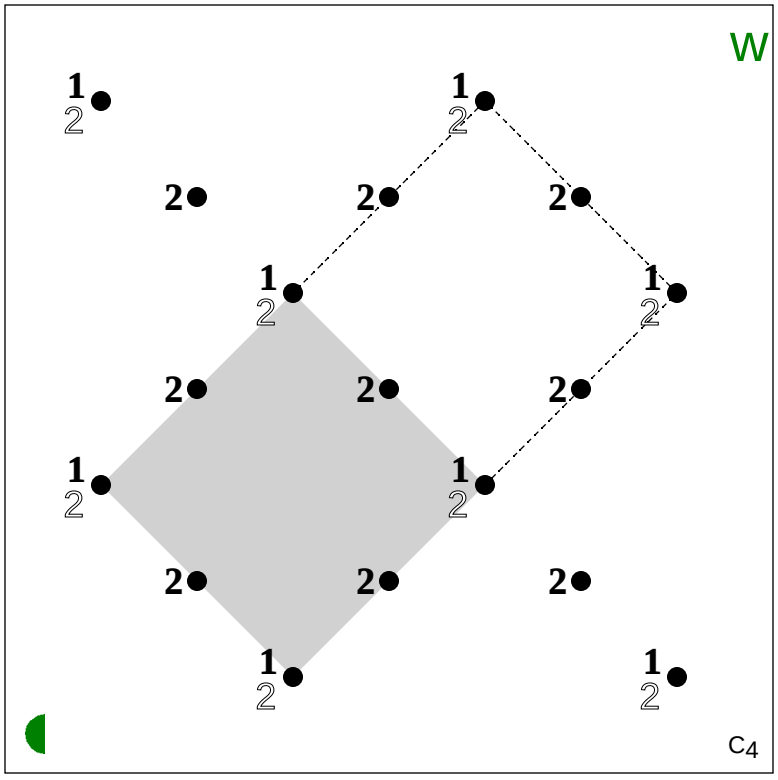
To build more than a unit cell:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

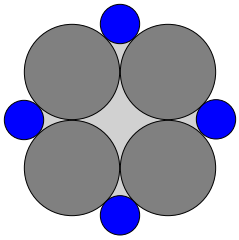
Template *C* (half-size)



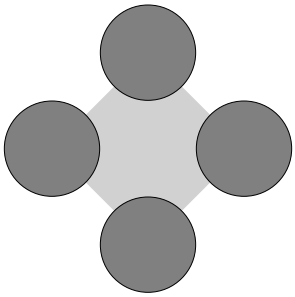
Pattern (actual size)



Unit cell layers (half-size)

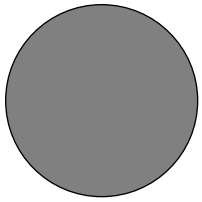


layer 2, z = 1/2



layer 1, z = 0

1, 2, 1' =



colorless

2 =

blue

K_2NiF_4

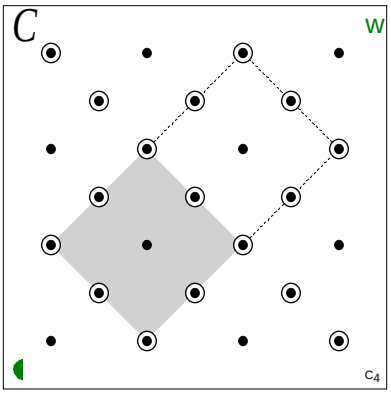
To build a unit cell:

- Position the W on template *C* in the same corner as the matching W on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, 0 through *2*, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

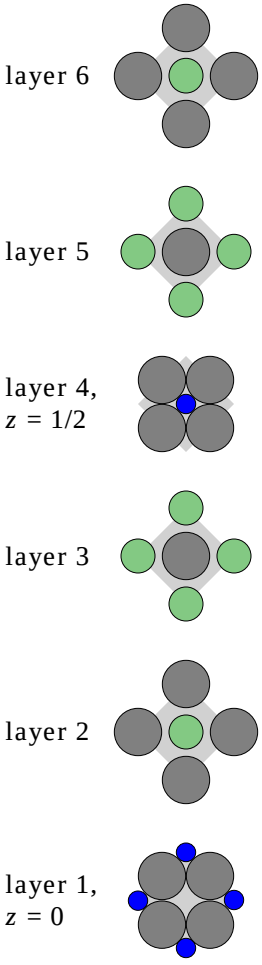
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

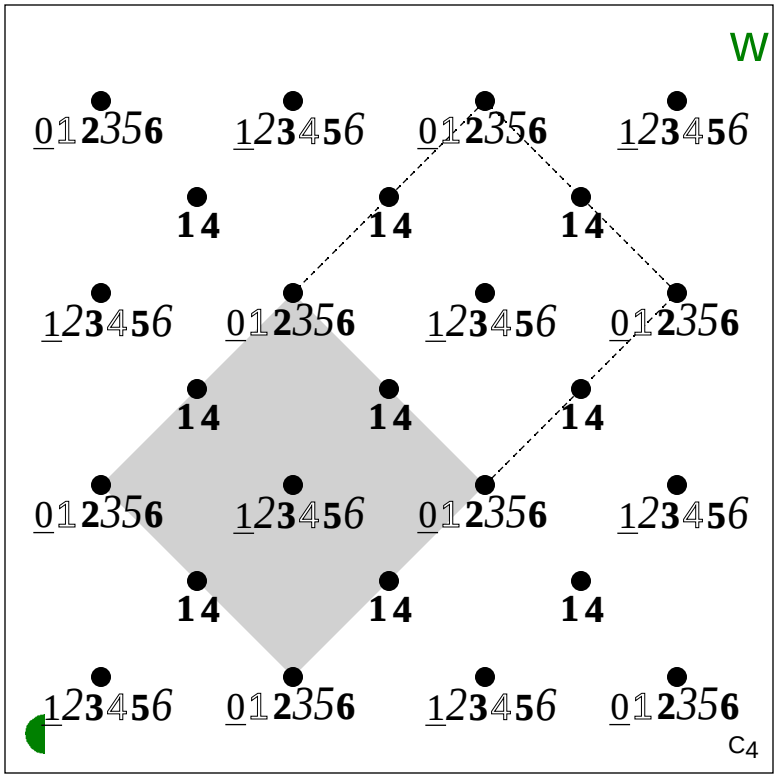
Template *C* (half-size)

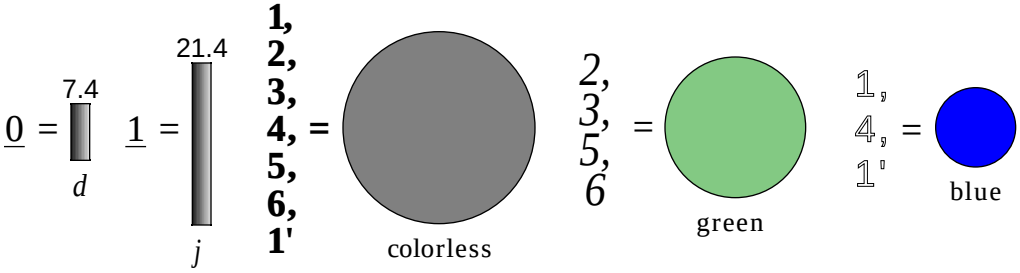


Unit cell layers (quarter-size)



Pattern (actual size)





$YBa_2Cu_3O_7$

- This model uses three different colors of the large spheres.

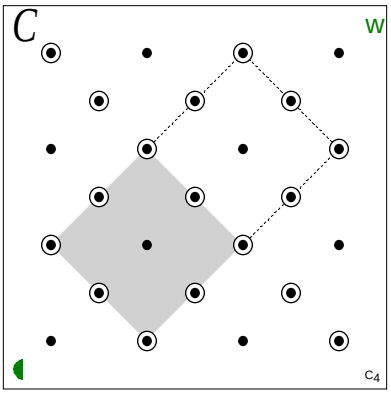
To build a unit cell:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, 0 through *6*, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

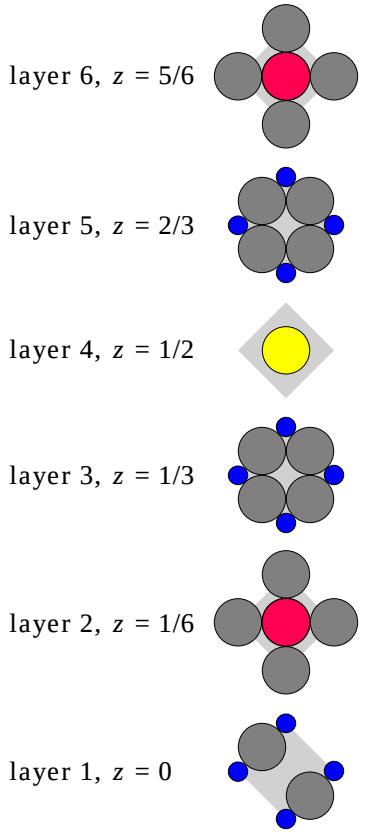
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

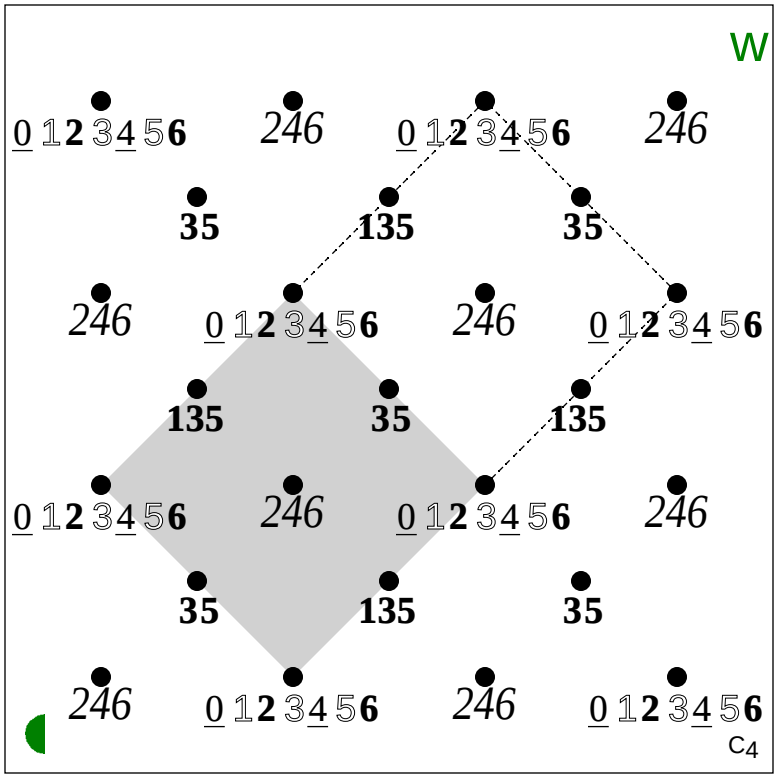
Template *C* (half-size)

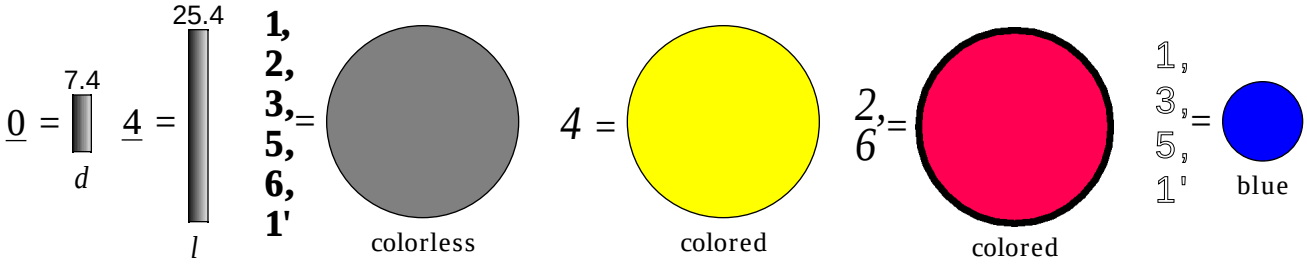


Unit cell layers (quarter-size)



Pattern (actual size)





$YBa_2Cu_3O_7$ (alternate)

- This model uses two different colors of the large spheres instead of three different large spheres; the smaller green sphere represents Ba.

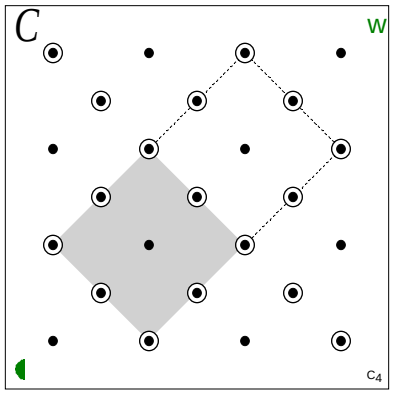
To build a unit cell:

- Position the won template *C* in the same corner as the matching won the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, 0 through *6*, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**, 1').

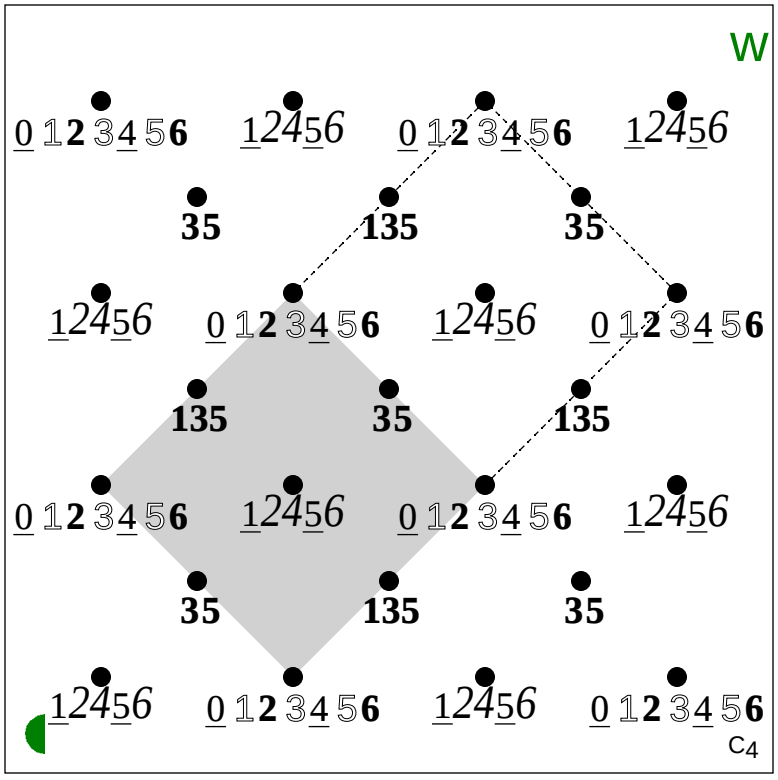
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

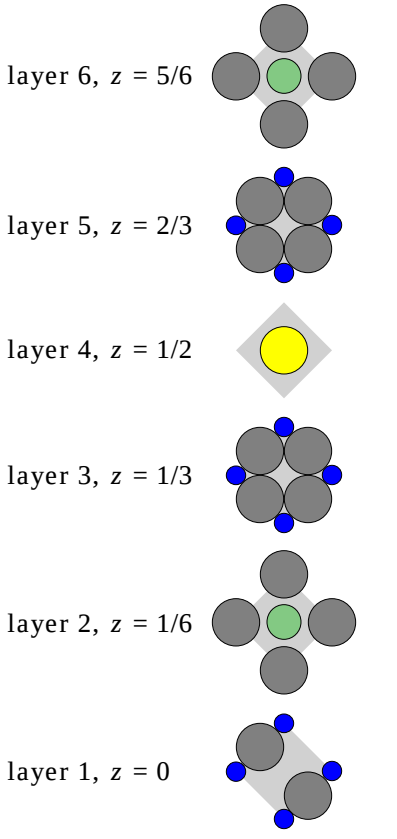
Template *C* (half-size)

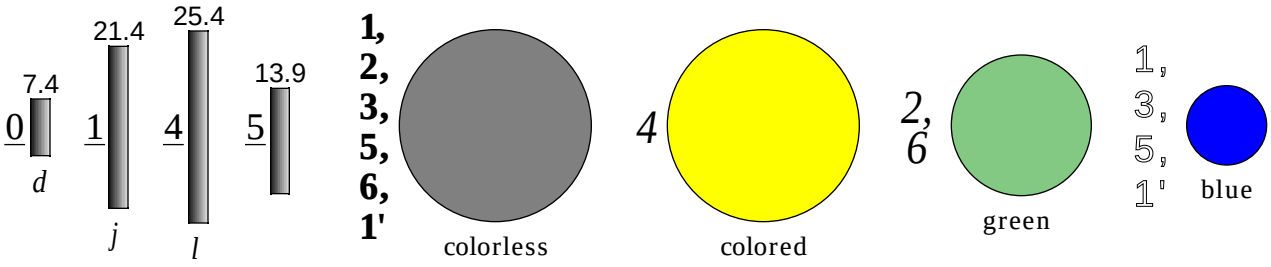


Pattern (actual size)



Unit cell layers (quarter-size)





$Tl_2Ba_2Ca_2Cu_3O_{10}$

- This model uses two different colors of the green and of the large spheres.

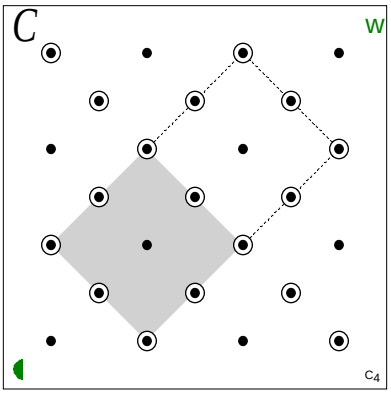
` To build half a unit cell tall:

- Position the w on template *C* in the same corner as the matching w on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, 0 through **12**, as described in the example directions. Finish each layer before starting the next layer.
- Since the unit cell is body centered, the second half of the unit cell is a repeat of the first half with a shift in origin.

To build more:

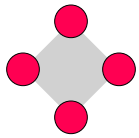
- Place rods in additional holes before placing spheres. Follow the same directions as above.

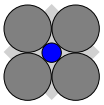
Template *C* (half-size)

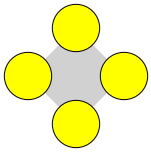


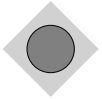
Unit cell layers (quarter-size)

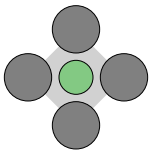
Note: the rods are only tall enough to build layers 1-12.

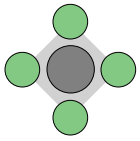

layer 15, 17

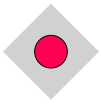

layer 14, 16, 18

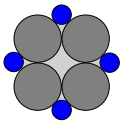

layer 13, 19

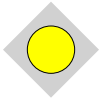

layer 12 (z=.5), 20

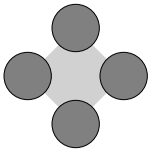

layer 11, 21


layer 10, 22

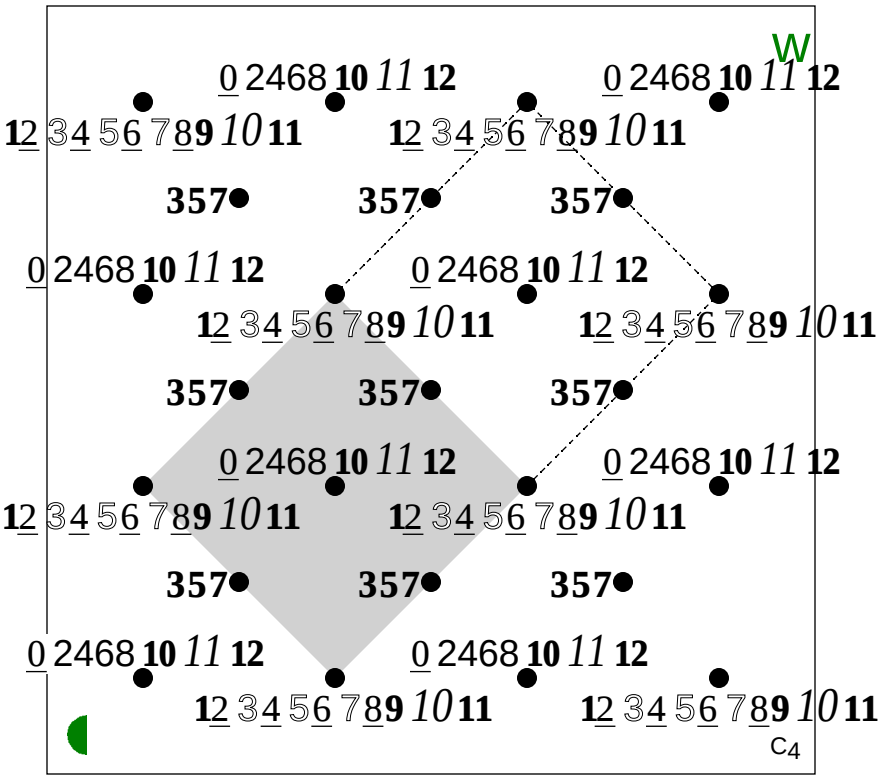

layer 4, 6

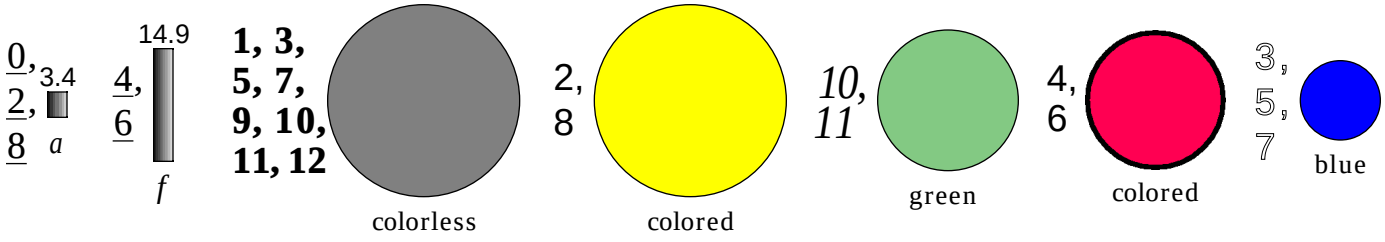

layer 3, 5, 7


layer 2, 8


layer 1, 9

Pattern (actual size)



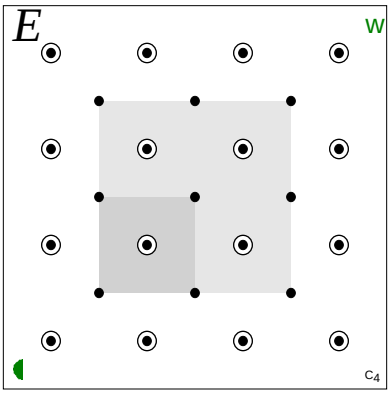


Spinel, $MgAl_2O_4$

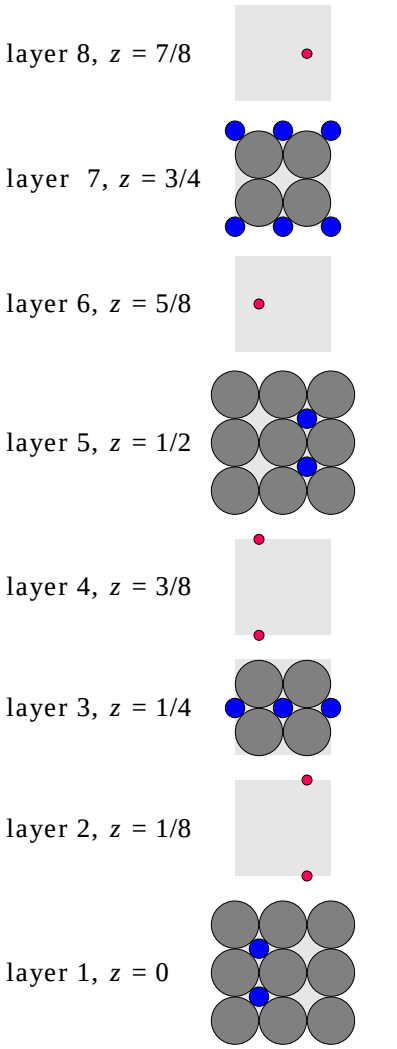
` To build the structure:

- Position the won template *E* in the same corner as the matching won the base and align holes.
- Insert rods in all 25 holes.
- Build layer 0 as described in the example directions. Build layer **1** next. Before placing layer 2 spheres, slide a row of large layer **3** spheres down their rods. Put a layer 2 sphere on the tip of an extra rod, tilt the model, lift a layer **3** sphere, and use the rod as a pointer to place the layer 2 sphere as shown below. Remove the pointer.
- Continue building the odd numbered layers in numerical order, placing the even numbered spheres as above. Finish each pair of layers before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

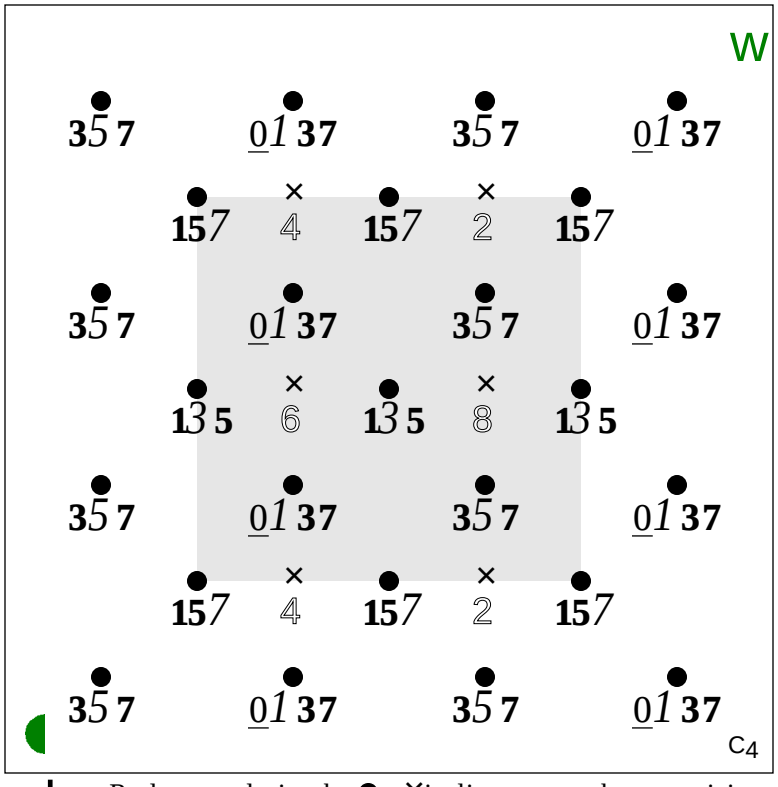
Template *E* (half-size)



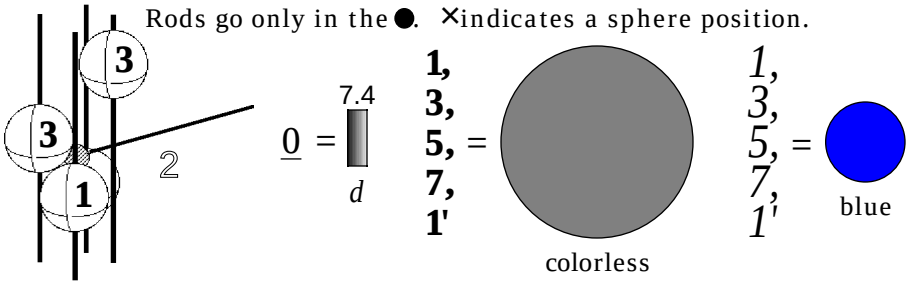
Unit cell layers (quarter-size)



Pattern (actual size)



Rods go only in the ●. ×indicates a sphere position.



Zinc Blende (cubic close-packed)

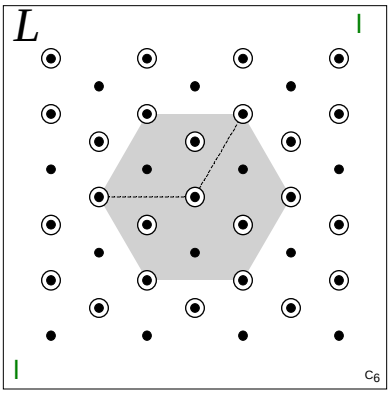
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 6, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

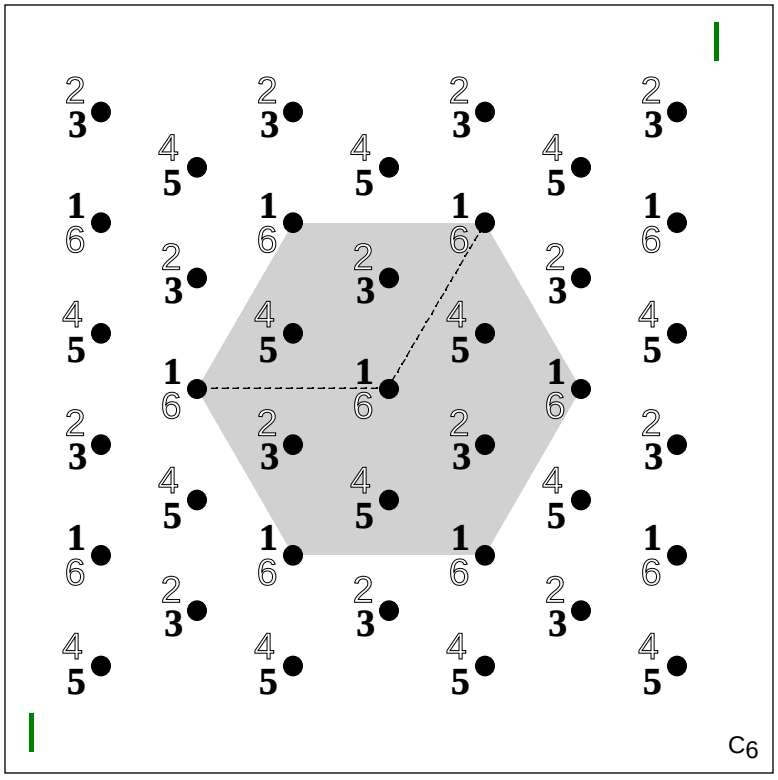
To build more than a hexagonal section:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

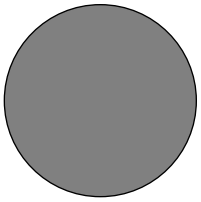
Template *L* (half-size)



Pattern (actual size)



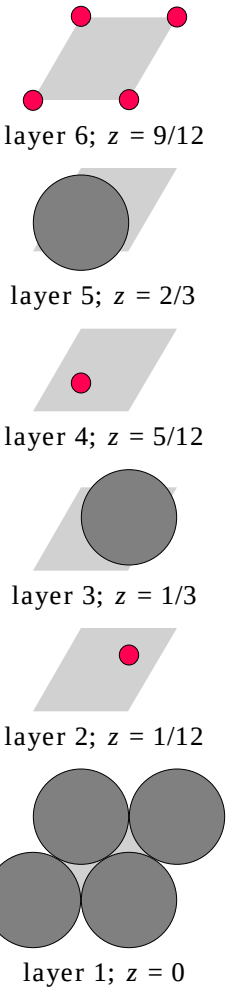
1, 3, 5, 1' =



colorless

2, 4, 6 = pink

Unit cell layers (half-size)

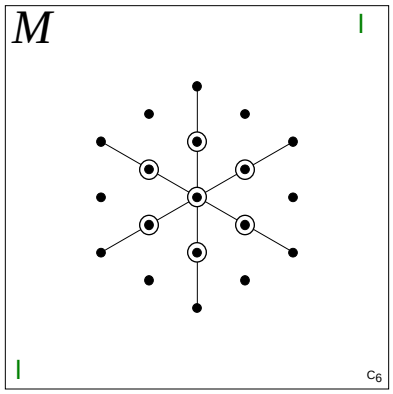


Zinc Blende (body diagonal)

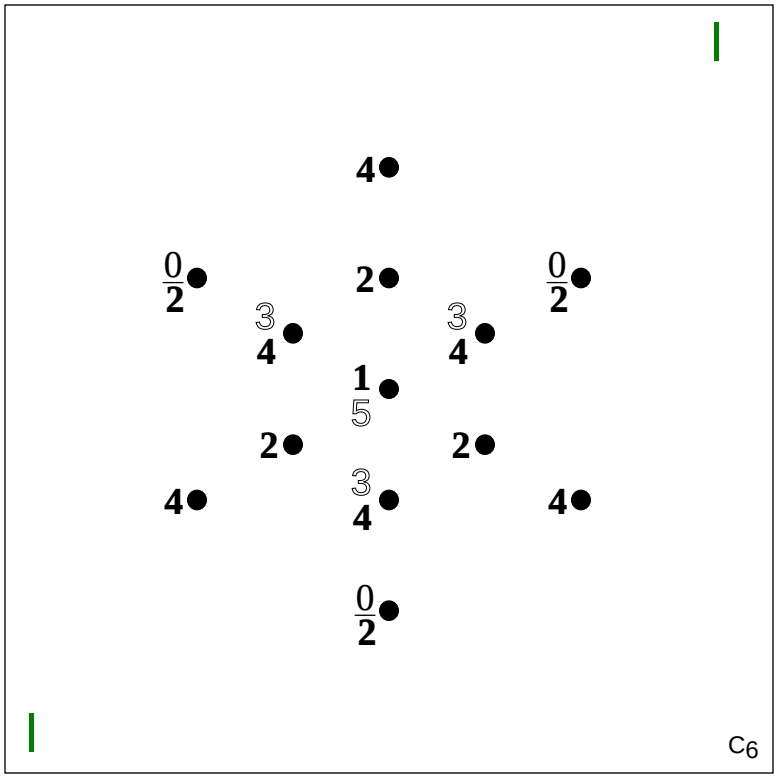
To build a unit cell:

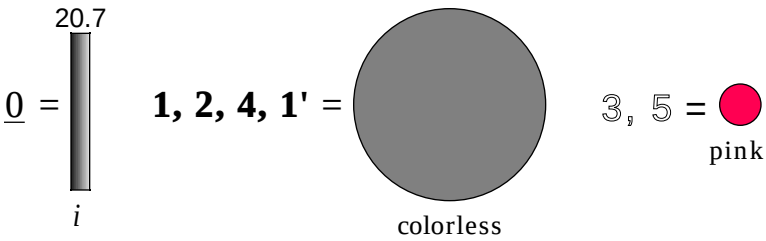
- Position the | on template *M* in the same corner as the matching | on the base and align holes.
- Insert rods in the 13 line-connected holes.
- Build each layer in numerical order, 0 through **5**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

Template M (half-size)

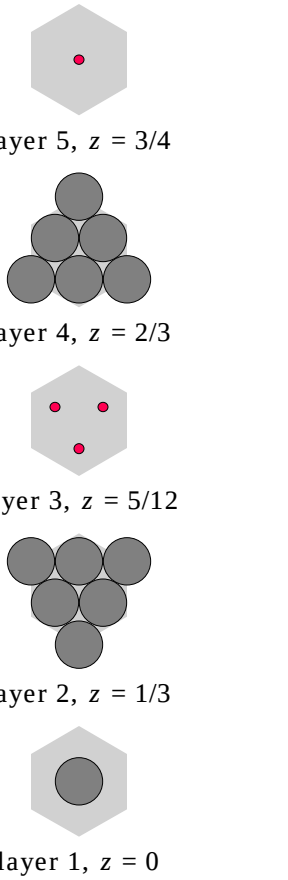


Pattern (actual size)





Unit cell layers (quarter-size)



Zinc Blende (face-centered cubic)

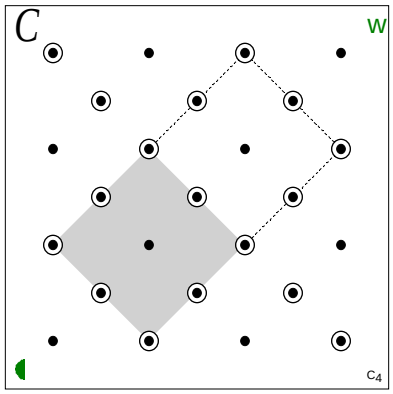
To build a unit cell:

- Position the won template *C* in the same corner as the matching won the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build layer **1** as described in the example directions. Before placing layer 2 spheres, slide a row of layer **3** spheres down their rods. Put a layer 2 sphere on the tip of an extra rod, tilt the model, lift a layer **3** sphere, and use the rod as a pointer to place the layer 2 sphere as shown below. Remove the pointer.
- Complete the unit cell by repeating the first layer (**1'**) and then placing the layer 4 spheres as above.

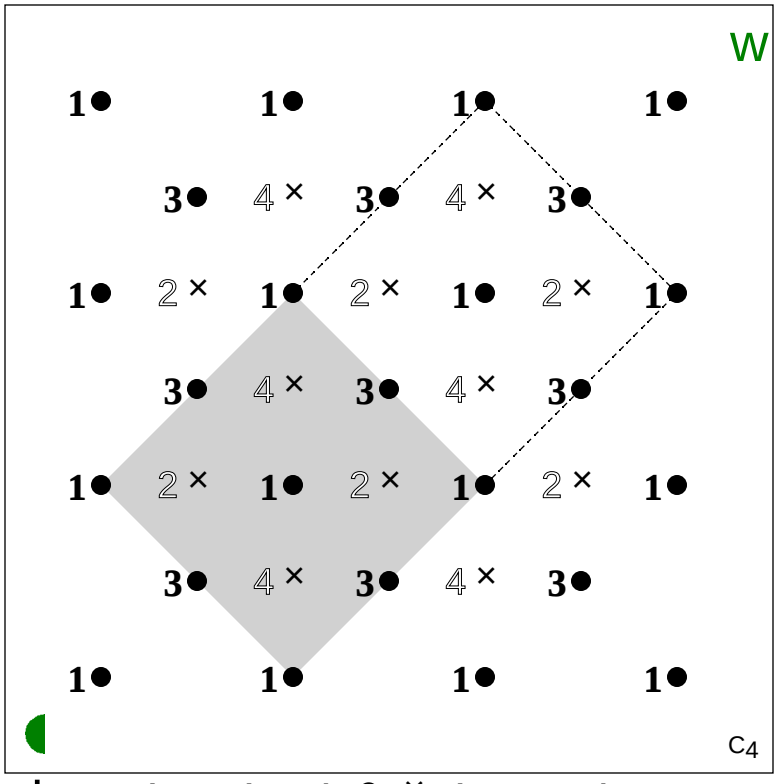
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

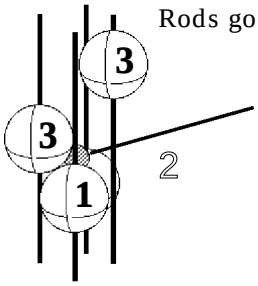
Template *C* (half-size)



Pattern (actual size)



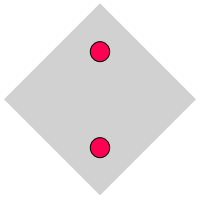
Rods go only in the ●. ×indicates a sphere position.



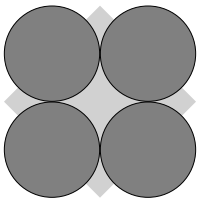
1, 3, 1' = colorless

2, 4 = pink

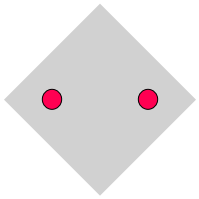
Unit cell layers (half-size)



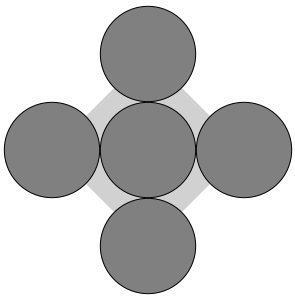
layer 4, *z* = 3/4



layer 3, *z* = 1/2



layer 2, *z* = 1/4



layer 1, *z* = 0

Zinc Blende (expanded fcc)

- The model is expanded since the largest spheres do not touch each other.

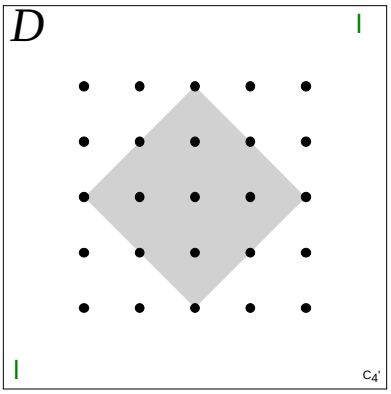
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

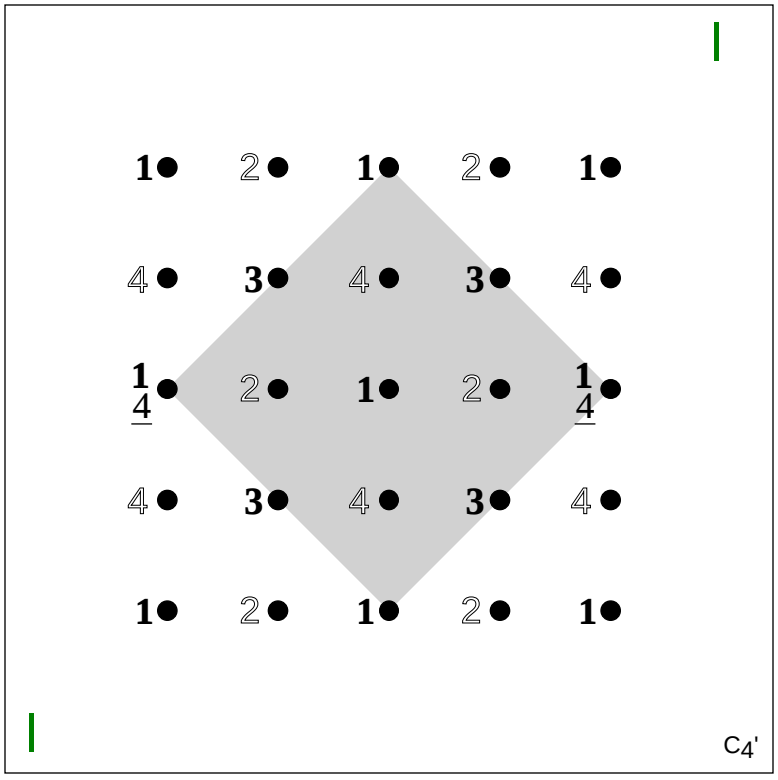
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above. The spacers are required only if you build just the shaded area.
- When building the structure higher, repeat the layers in order.

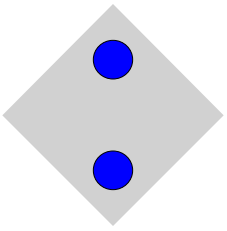
Template *D* (half-size)



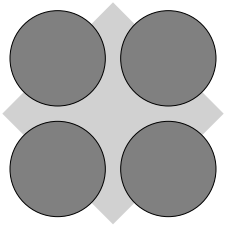
Pattern (actual size)



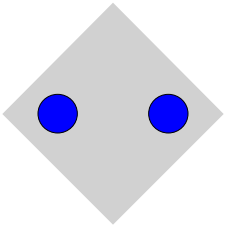
Unit cell layers (half-size)



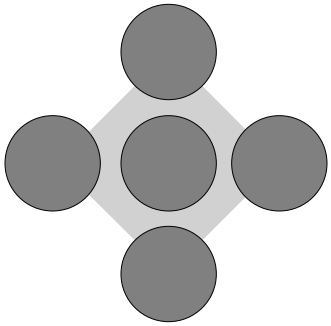
layer 4, z = 3/4



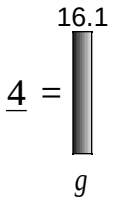
layer 3, z = 1/2

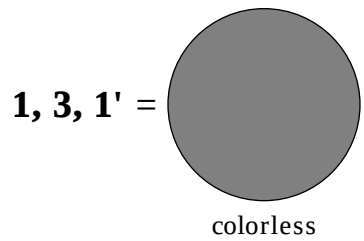


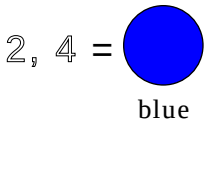
layer 2, z = 1/4



layer 1, z = 0







Zinc Blende (doubly expanded fcc)

- The model is doubly expanded since the smaller spheres are two sizes larger than that which allows the largest spheres to touch.

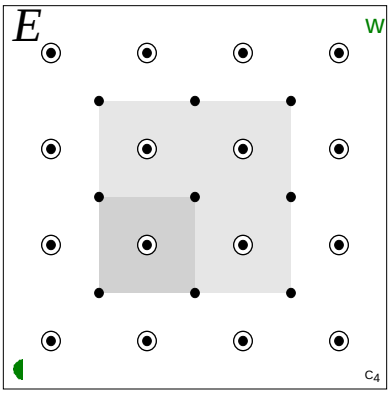
To build a unit cell:

- Position the w on template *E* in the same corner as the matching w on the base and align holes.
- Insert rods in all 13 holes in the entire shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

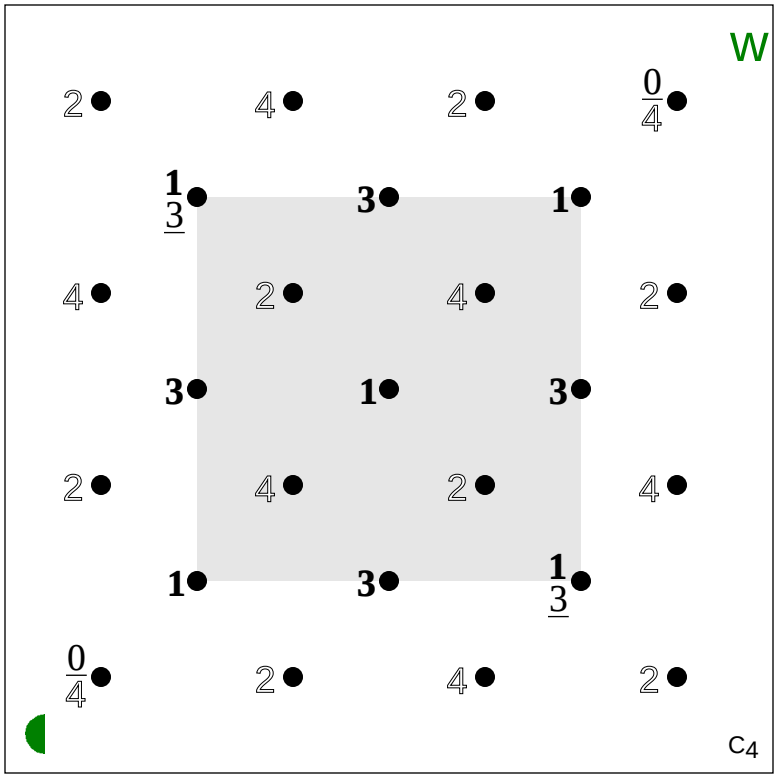
To build more than a unit cell:

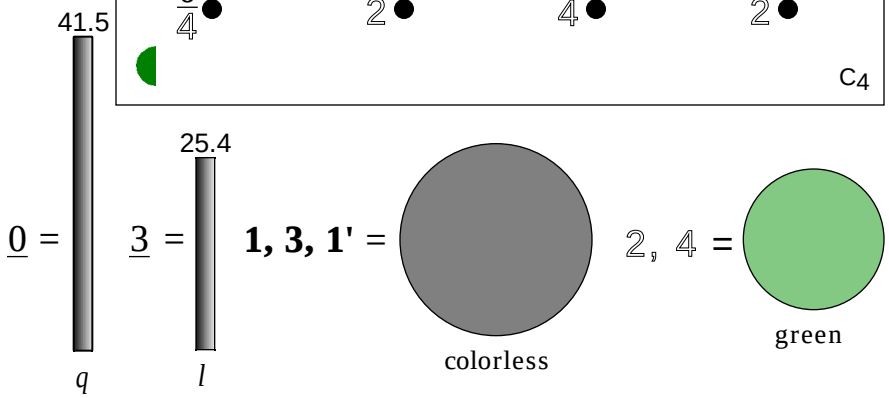
- Place rods in additional holes before placing spheres. Begin with spacer 0; follow the same directions as above.
- When building the structure higher, repeat the layers in order.

Template *E* (half-size)

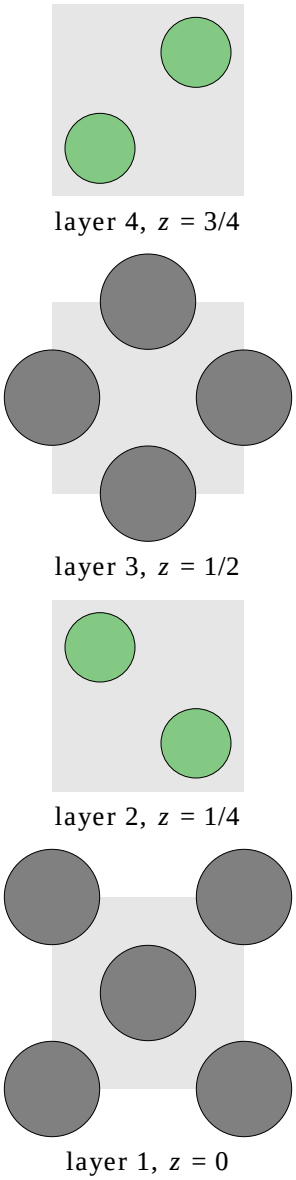


Pattern (actual size)





Unit cell layers (half-size)



Wurtzite

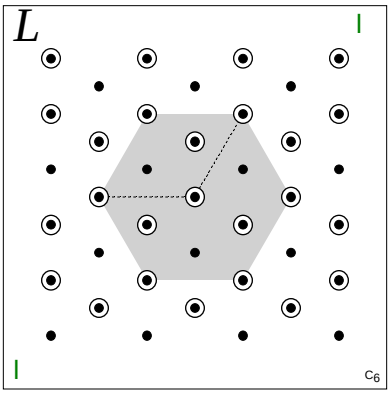
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in the 10 circled holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

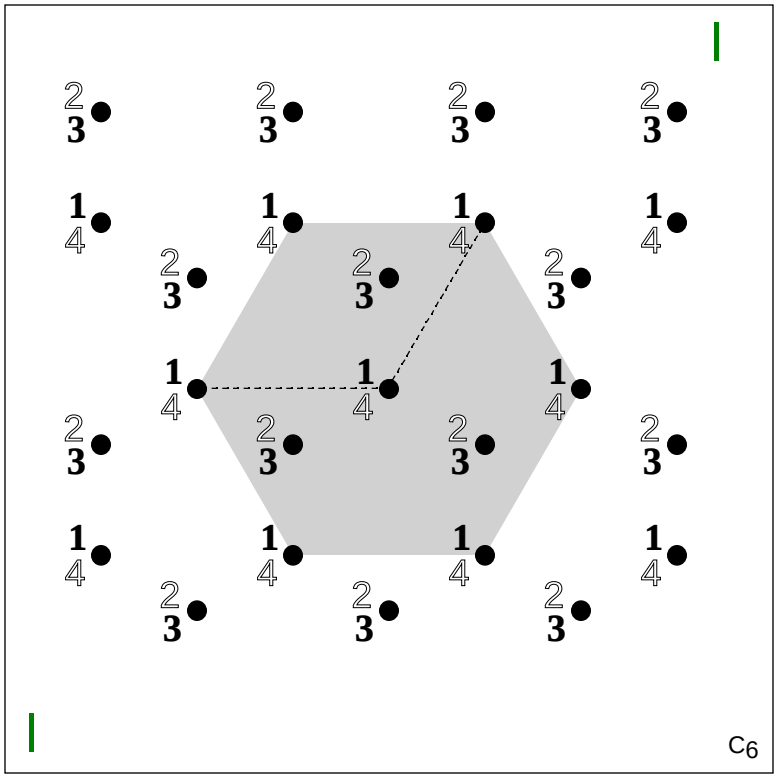
To build more than a hexagonal section:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

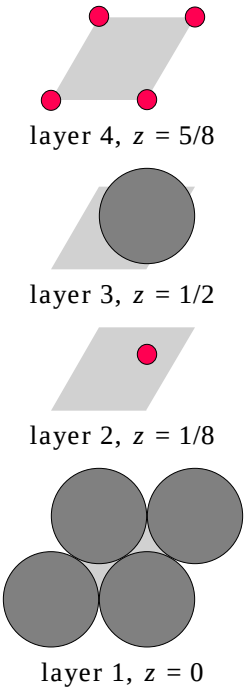
Template *L* (half-size)



Pattern (actual size)



Unit cell layers (half-size)



1, 3, 1' = colorless

2, 4 = pink

Wurtzite (expanded)

- The model is expanded since the largest spheres do not touch each other.

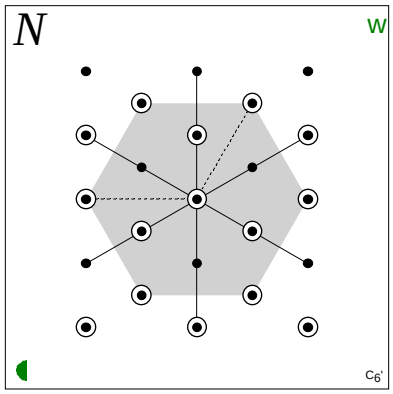
To build a hexagonal section:

- Position the won template *N* in the same corner as the matching won the base and align holes.
- Insert rods in the 10 circled holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

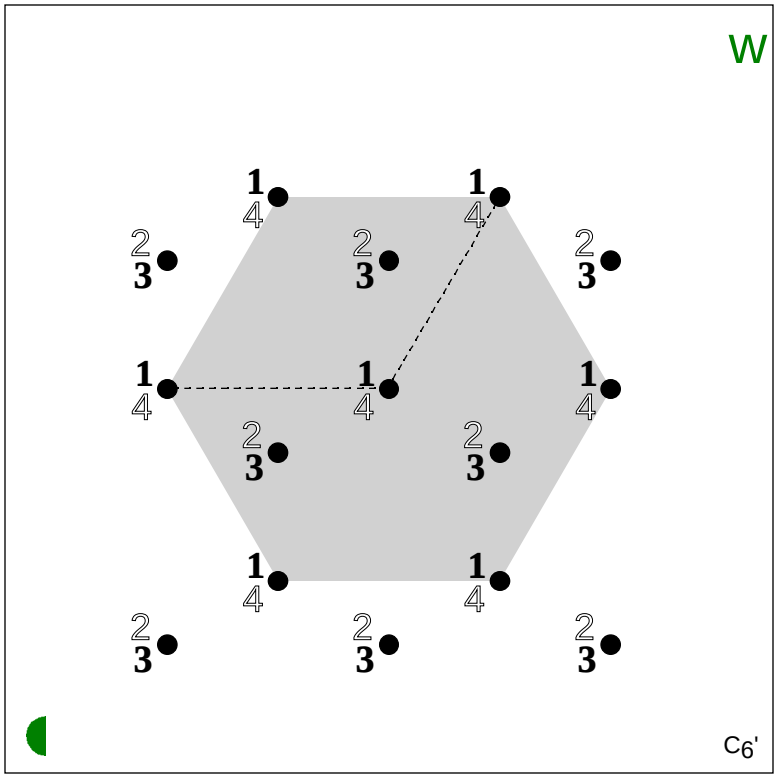
To build more than a hexagonal section:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

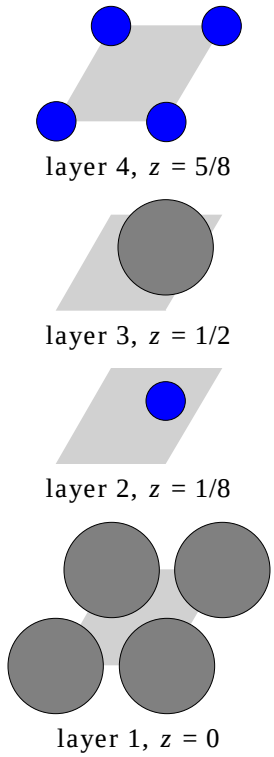
Template *N* (half-size)



Pattern (actual size)



Unit cell layers (half-size)



1, 3, 1' = colorless

2, 4 = blue

Anti-fluorite (cubic close-packed)

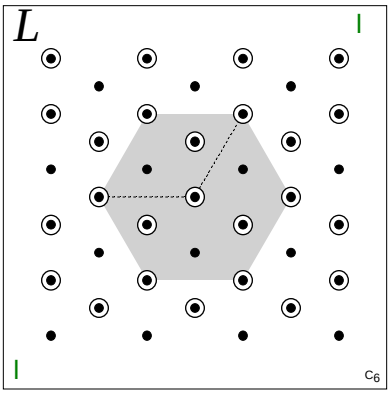
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 9, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

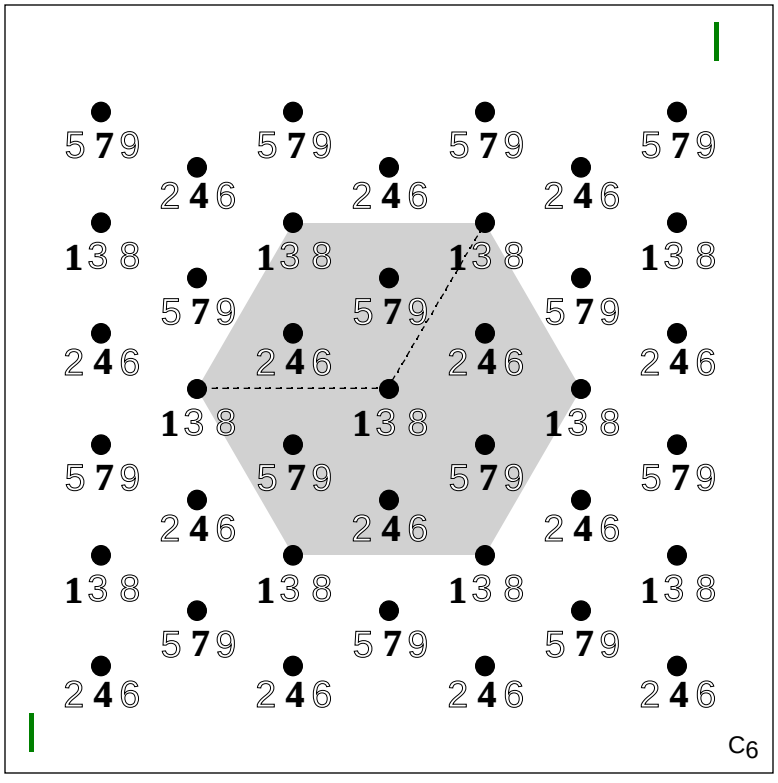
To build more than a hexagonal section:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

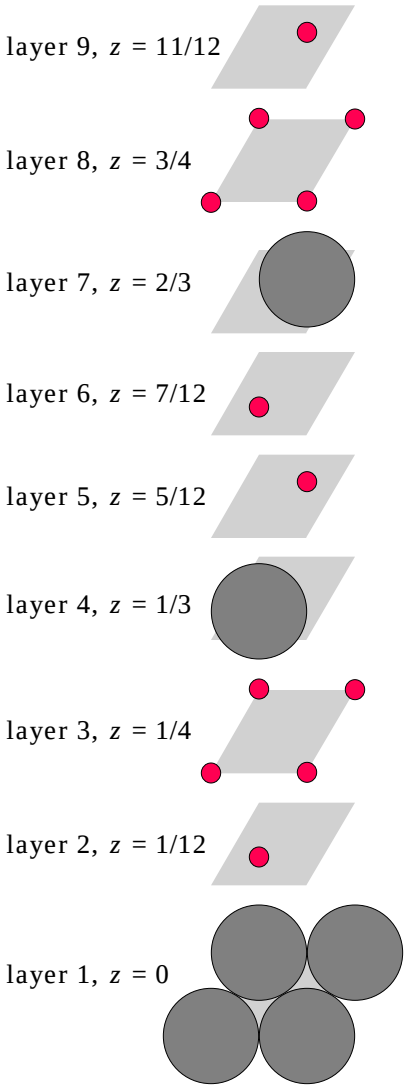
Template *L* (half-size)



Pattern (actual size)



Unit cell layers (half-size)



1, 4, 7, 1' = colorless

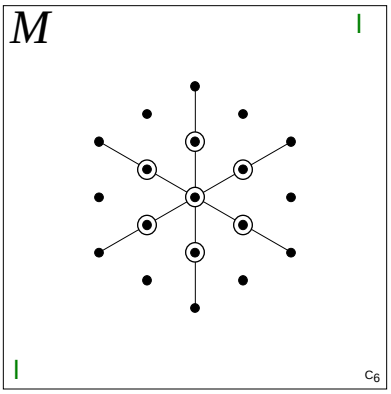
2, 3, 5, 6, 8, 9 = pink

Anti-fluorite (body diagonal)

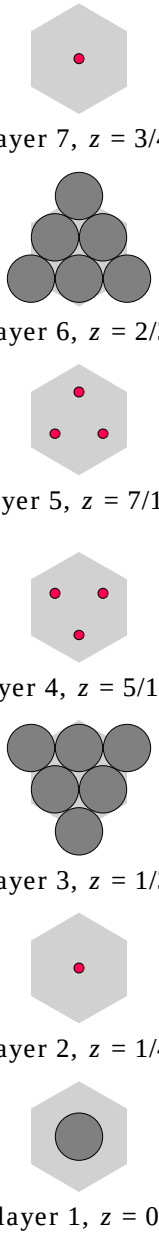
To build a unit cell:

- Position the | on template *M* in the same corner as the matching | on the base and align holes.
- Insert rods in the 13 line-connected holes.
- Build each layer in numerical order, 0 through 7, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

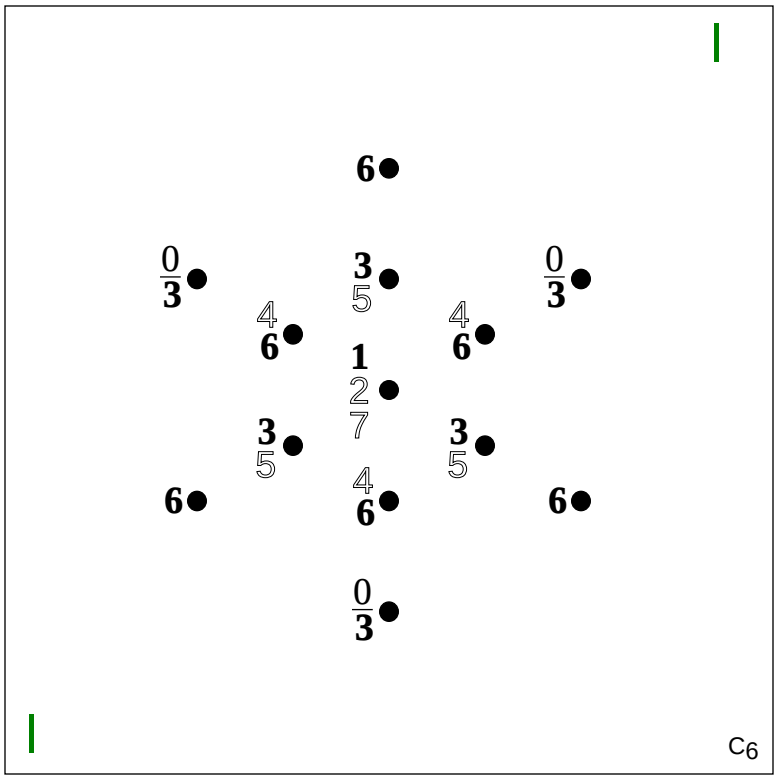
Template M (half-size)

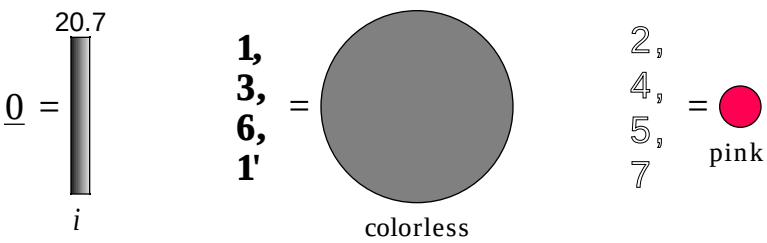


Unit cell layers (quarter-size)



Pattern (actual size)





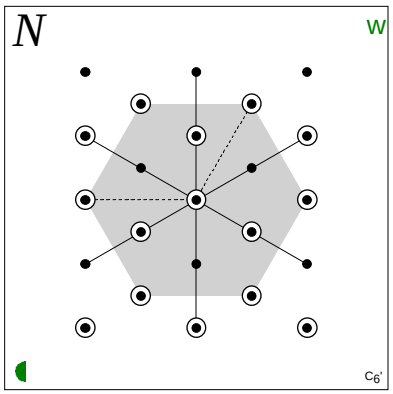
Anti-fluorite (expanded body diagonal)

- The model is expanded since the largest spheres do not touch each other.

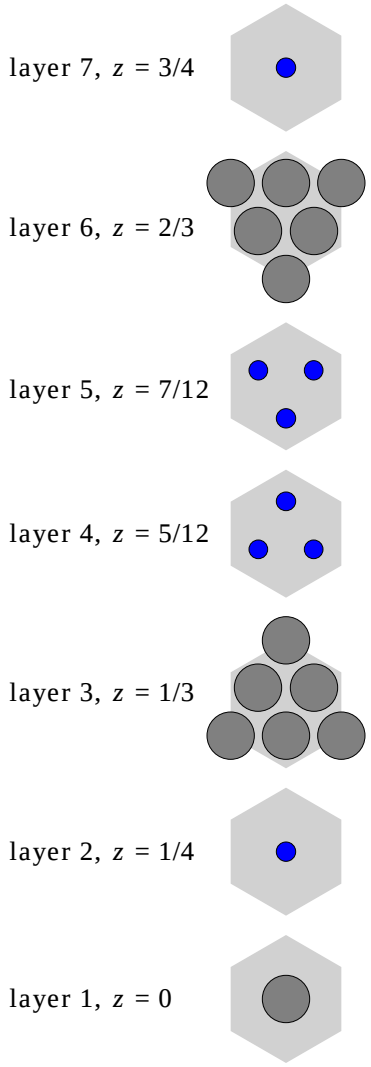
To build a unit cell:

- Position the w on template *N* in the same corner as the matching w on the base and align holes.
- Insert rods in the 13 solid line-connected holes.
- Build each layer in numerical order, 0 through 7, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

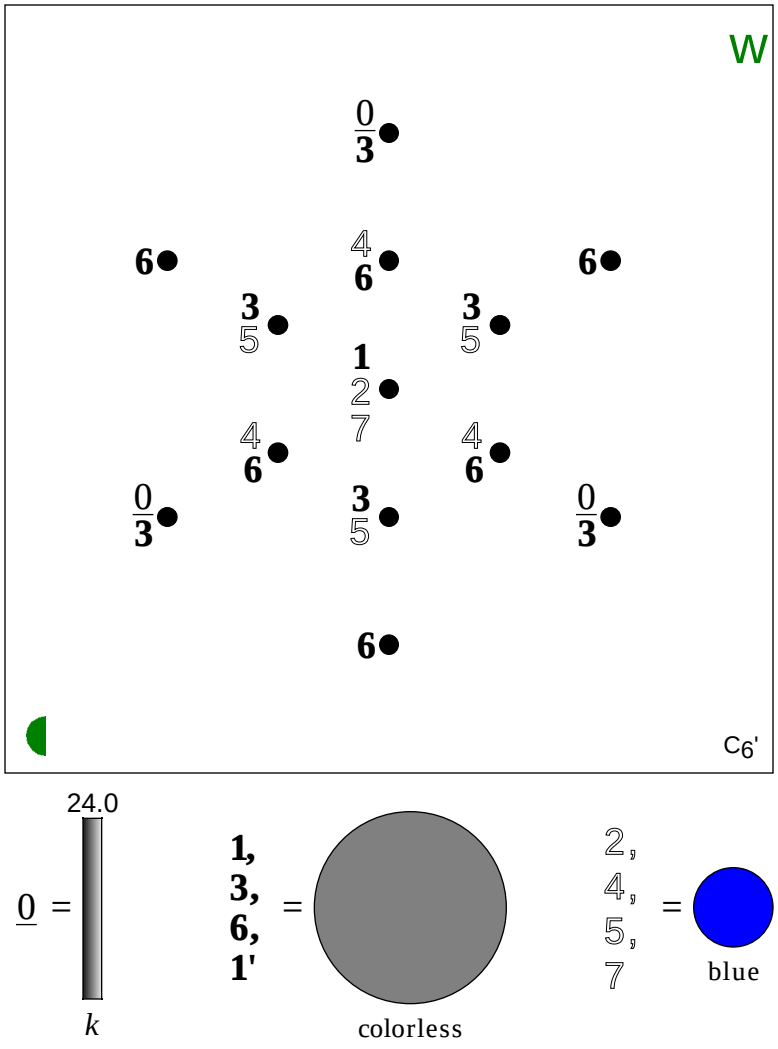
Template *N* (half-size)



Unit cell layers (quarter-size)



Pattern (actual size)



Anti-fluorite (face-centered cubic)

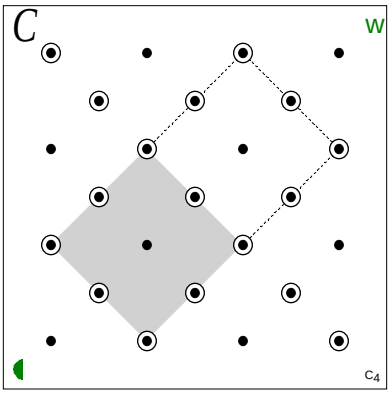
To build a unit cell:

- Position the won template *C* in the same corner as the matching won the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build layer **1** as described in the example directions. Before placing layer 2 spheres, slide a row of layer **3** spheres down their rods. Put a layer 2 sphere on the tip of an extra rod, tilt the model, lift a layer **3** sphere, and use the rod as a pointer to place the layer 2 sphere as shown below. Remove the pointer.
- Complete the unit cell by repeating the first layer (**1'**) and then placing the layer 4 spheres as above.

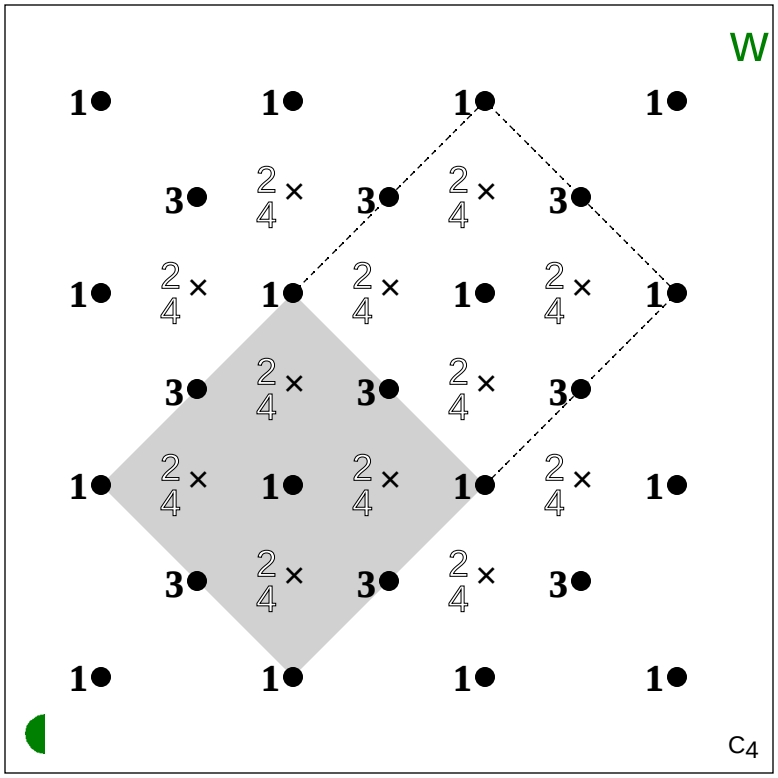
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

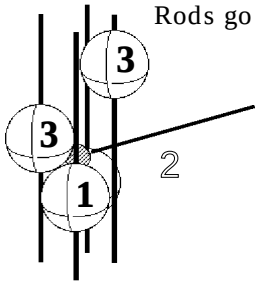
Template *C* (half-size)



Pattern (actual size)



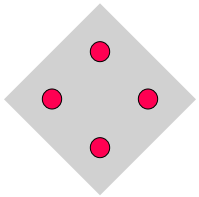
Rods go only in the ●. ×indicates a sphere position.



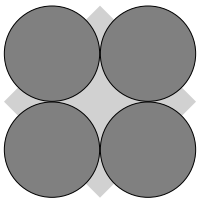
1, 3, 1' = colorless

2, 4 = pink

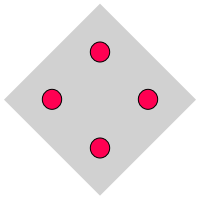
Unit cell layers (half-size)



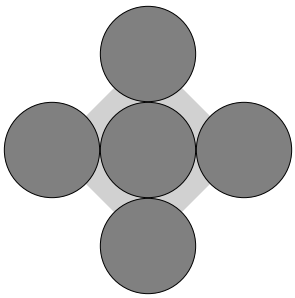
layer 4, *z* = 3/4



layer 3, *z* = 1/2



layer 2, *z* = 1/4



layer 1, *z* = 0

Anti-fluorite (expanded fcc)

- The model is expanded since the largest spheres do not touch each other.

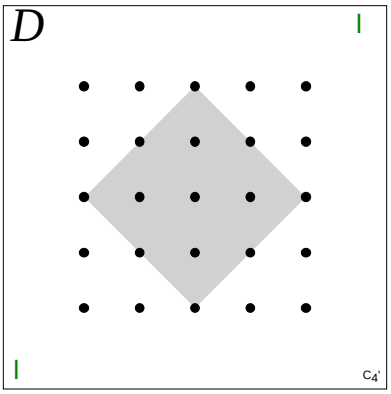
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

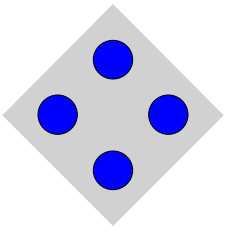
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

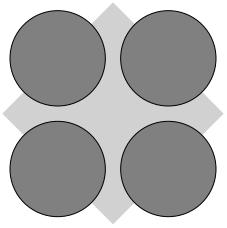
Template *D* (half-size)



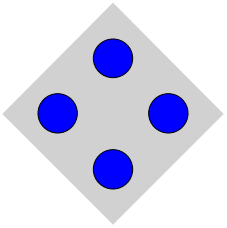
Unit cell layers (half-size)



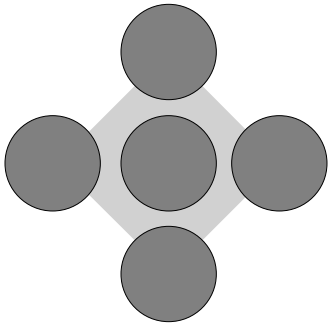
layer 4, *z* = 3/4



layer 3, *z* = 1/2

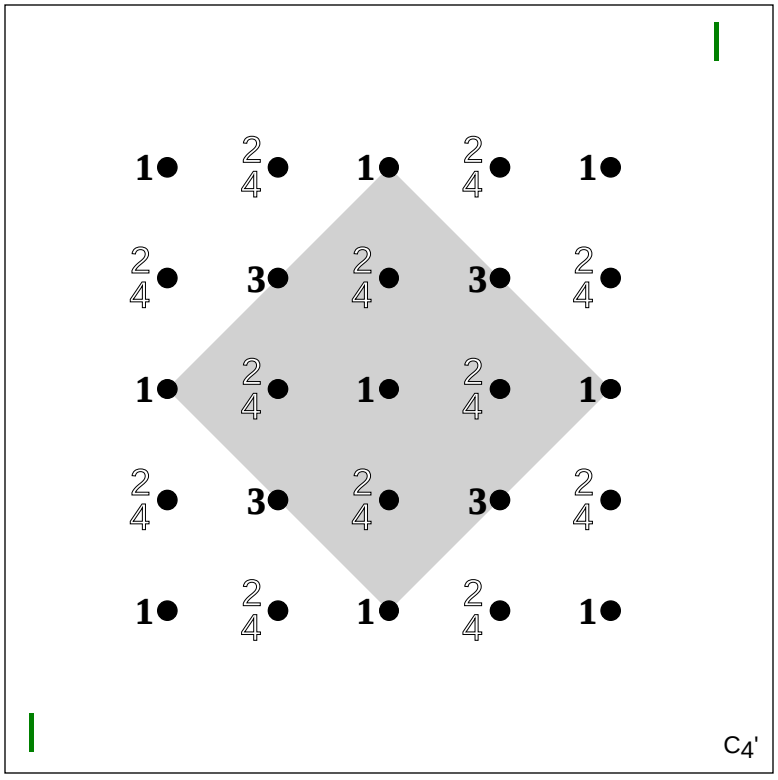


layer 2, *z* = 1/4

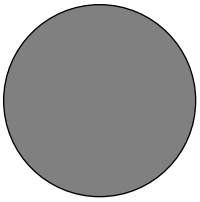


layer 1, *z* = 0

Pattern (actual size)



1, 3, 1' =



colorless

2, 4 =

blue

Anti-fluorite (doubly expanded fcc)

- The model is doubly expanded since the smaller spheres are two sizes larger than that which allows the largest spheres to touch.

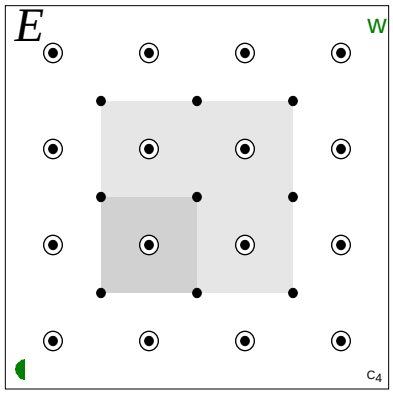
To build a unit cell:

- Position the won template E in the same corner as the matching won the base and align holes.
- Insert rods in all 13 holes in the entire shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

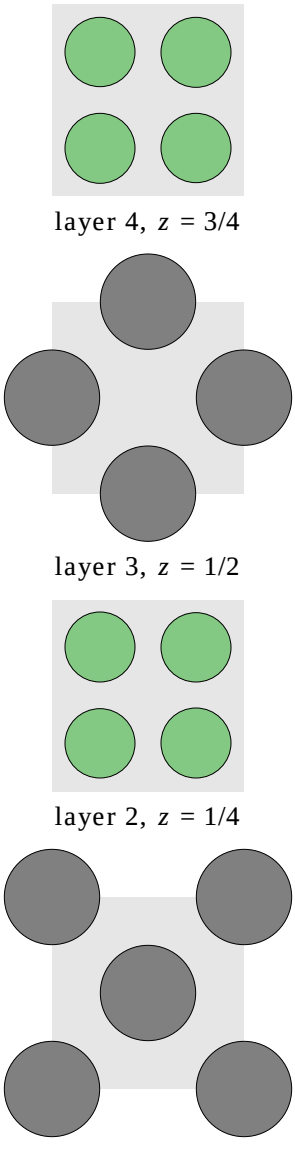
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

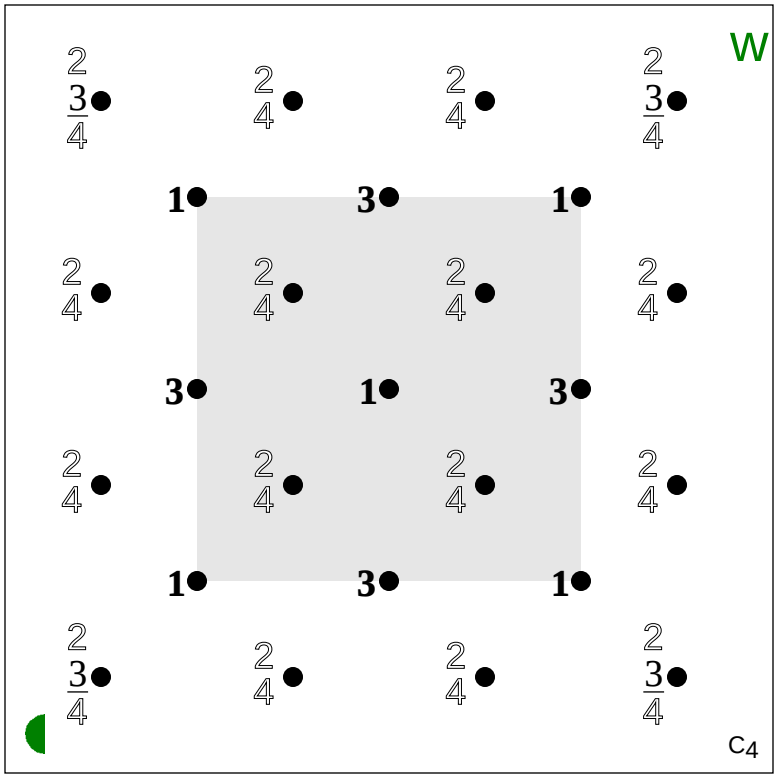
Template E (half-size)

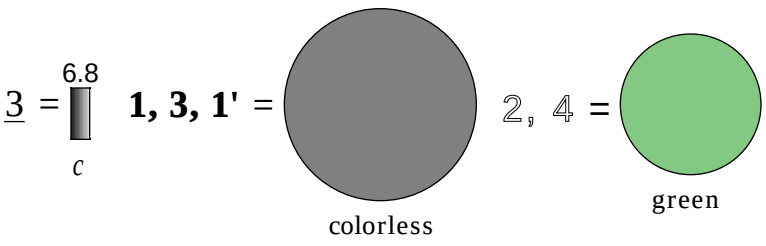


Unit cell layers (half-size)



Pattern (actual size)





MgAgAs (expanded)

- This model uses two different colors of the blue-size spheres.

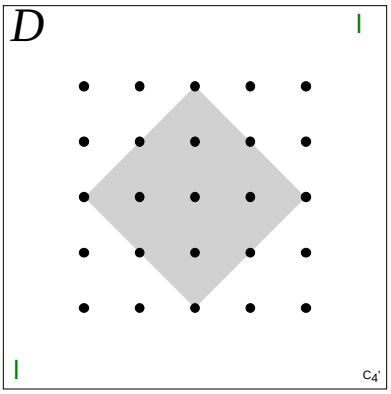
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

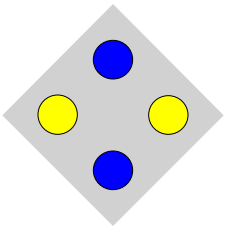
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

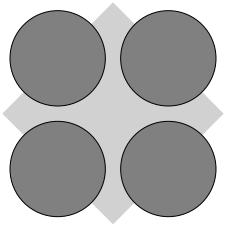
Template *D* (half-size)



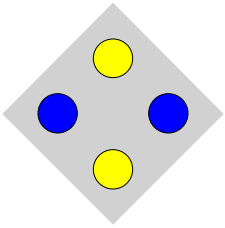
Unit cell layers (half-size)



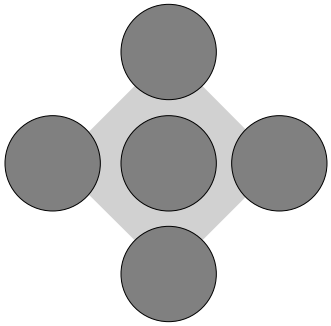
layer 4, *z* = 3/4



layer 3, *z* = 1/2

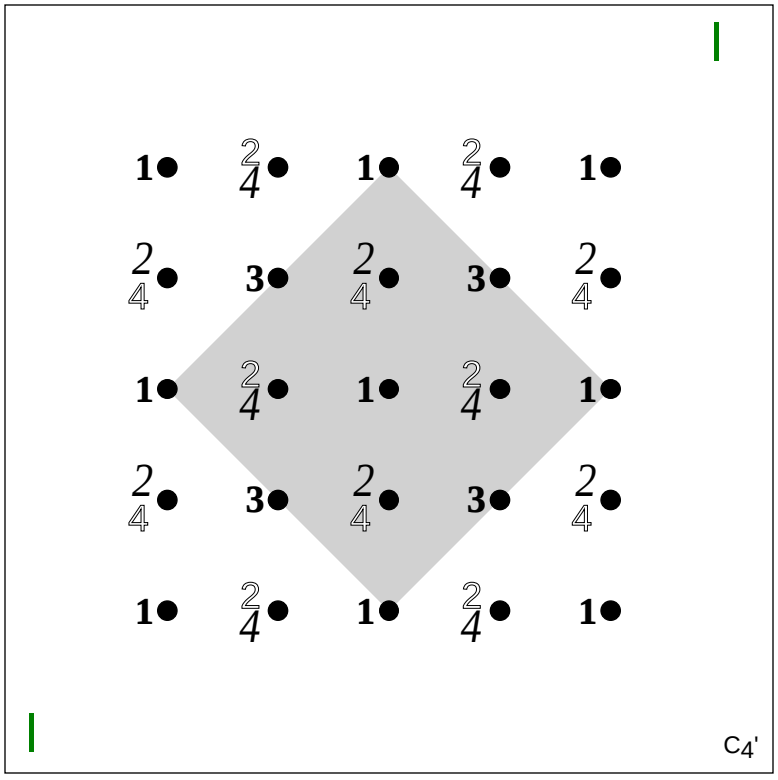


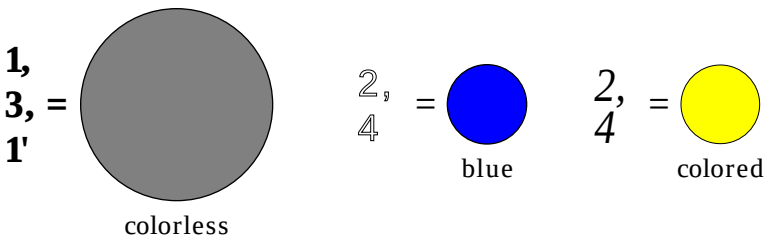
layer 2, *z* = 1/4



layer 1, *z* = 0

Pattern (actual size)





Chalcopyrite, $CuFeS_2$ (expanded)

- This model uses two different colors of the blue-size spheres.

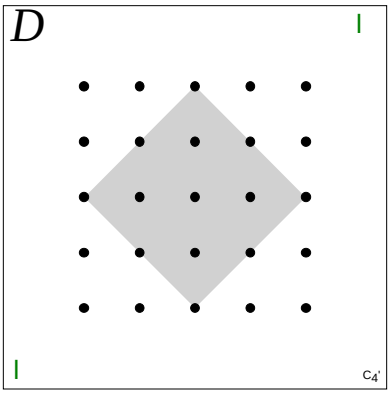
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

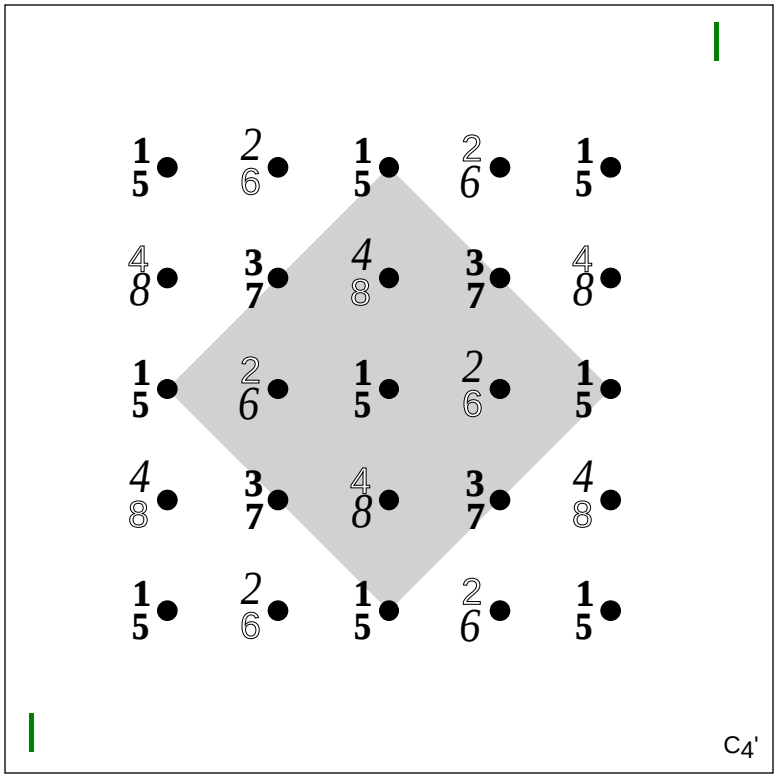
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

Template *D* (half-size)



Pattern (actual size)

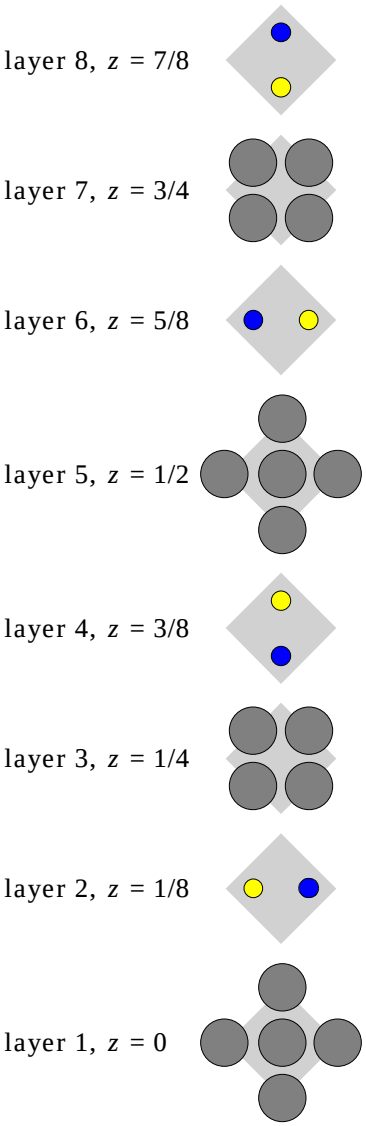


1, 3, 1' = colorless

2, 4, 6, 8 = blue

2, 4, 6, 8 = colored

Unit cell layers (quarter-size)



Stannite, Cu_2FeSnS_4 (expanded)

- This model uses three different colors of the blue-size spheres.

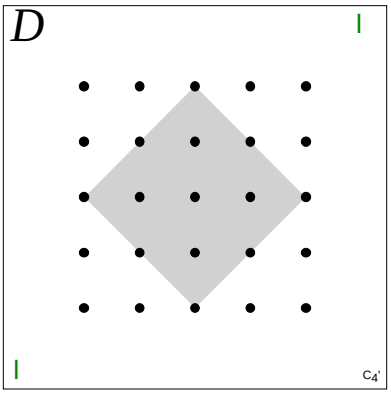
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through *8*, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

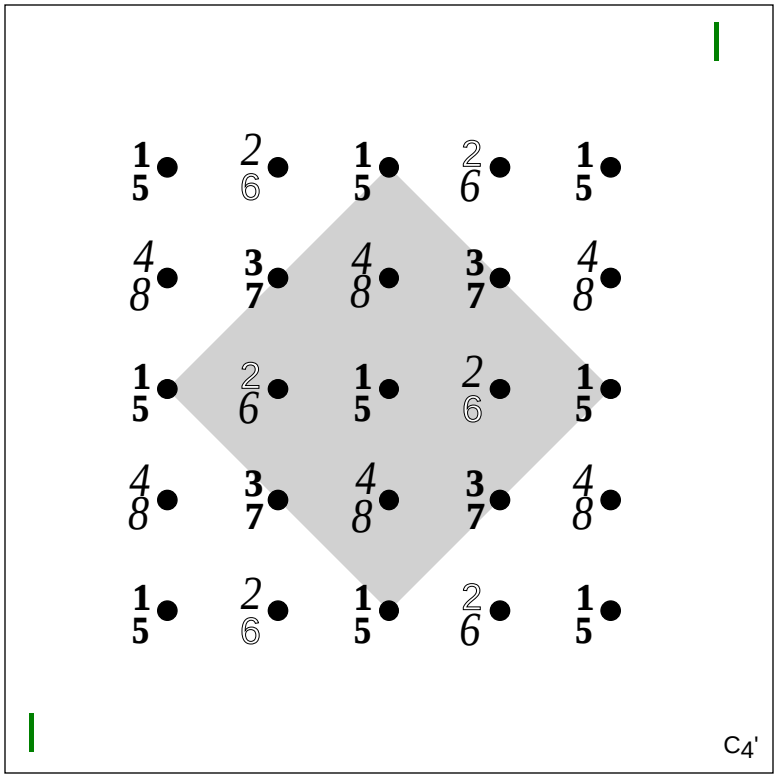
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

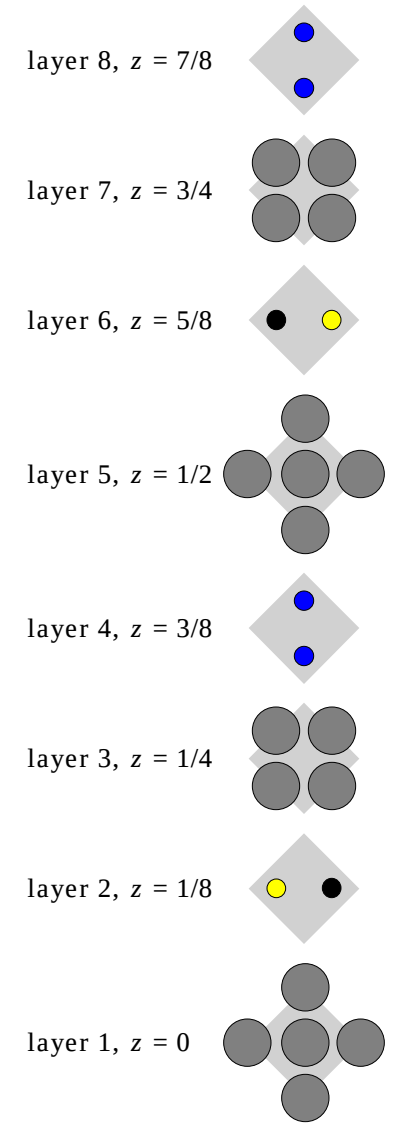
Template *D* (half-size)



Pattern (actual size)



Unit cell layers (quarter-size)



1, 3, 1' = colorless

4, 8 = blue

2, 6 = colored

2, 6 = colored

Cu_2HgI_4 (expanded)

- This model uses two different colors of the blue-size spheres.

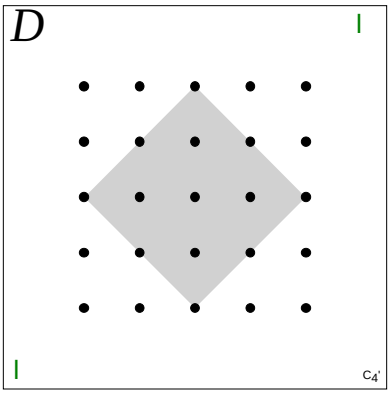
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

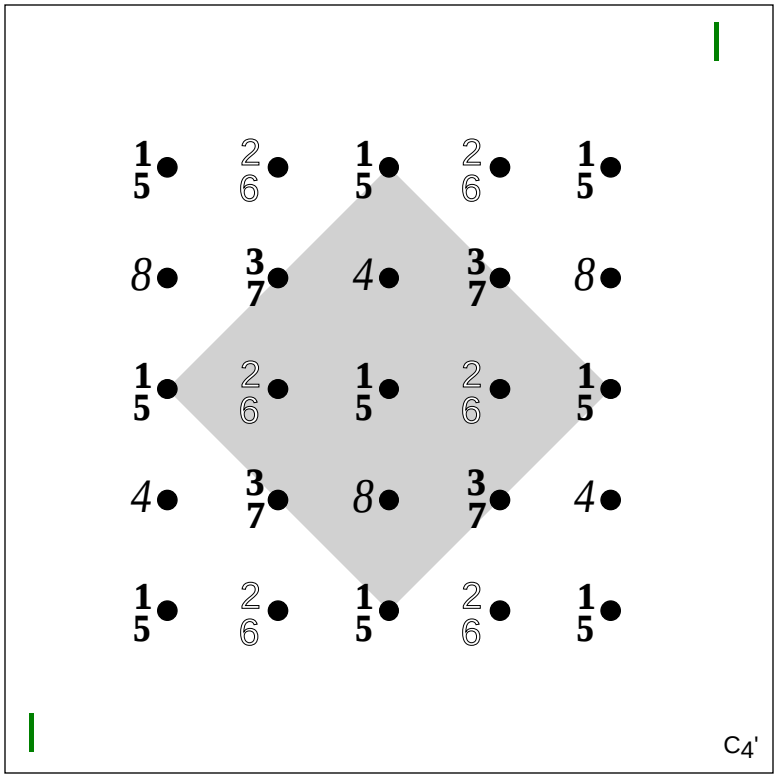
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

Template *D* (half-size)



Pattern (actual size)

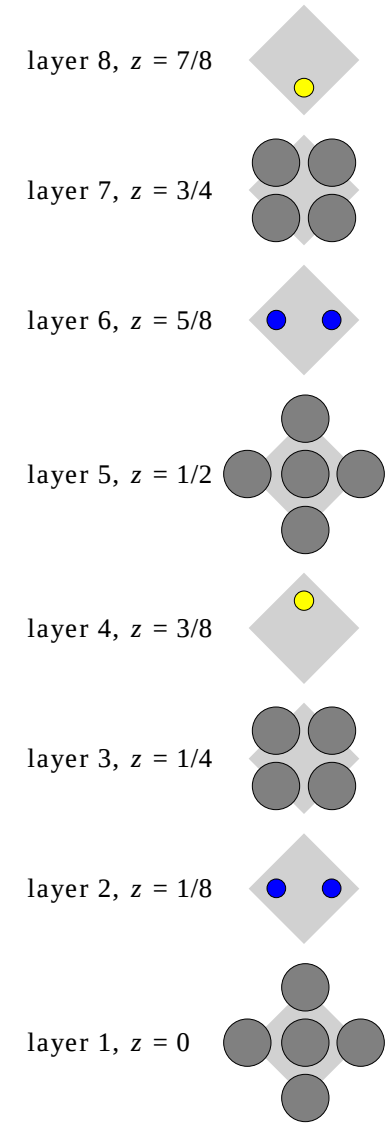


1, 3, 1' = colorless

2, 4 = blue

4, 8 = colored

Unit cell layers (quarter-size)



Ag_2HgI_4 (expanded)

- This model uses two different colors of the blue-size spheres.

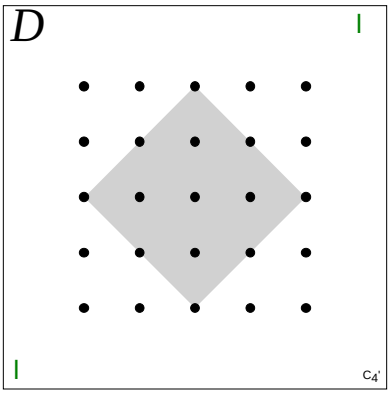
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

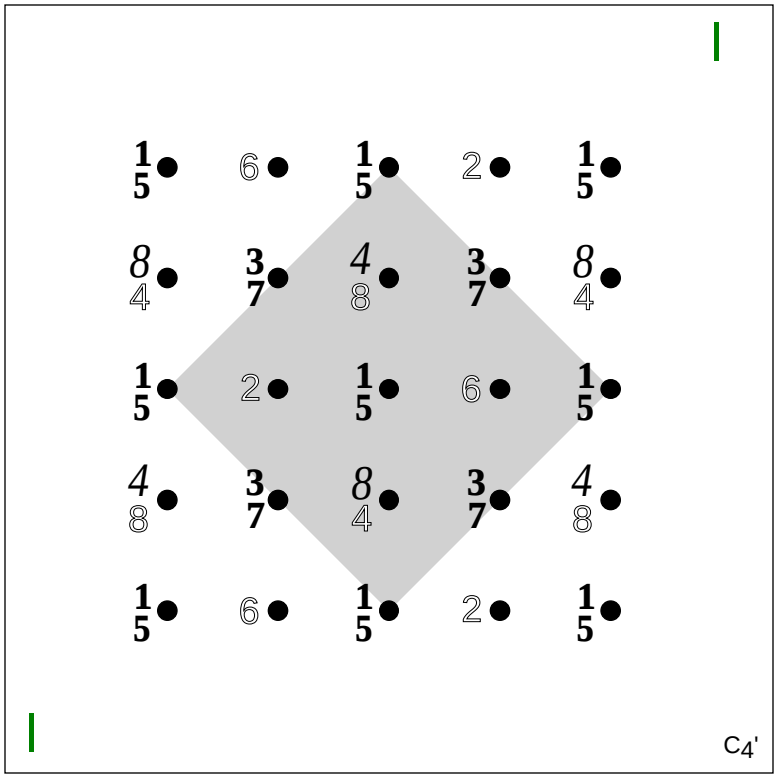
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

Template *D* (half-size)



Pattern (actual size)

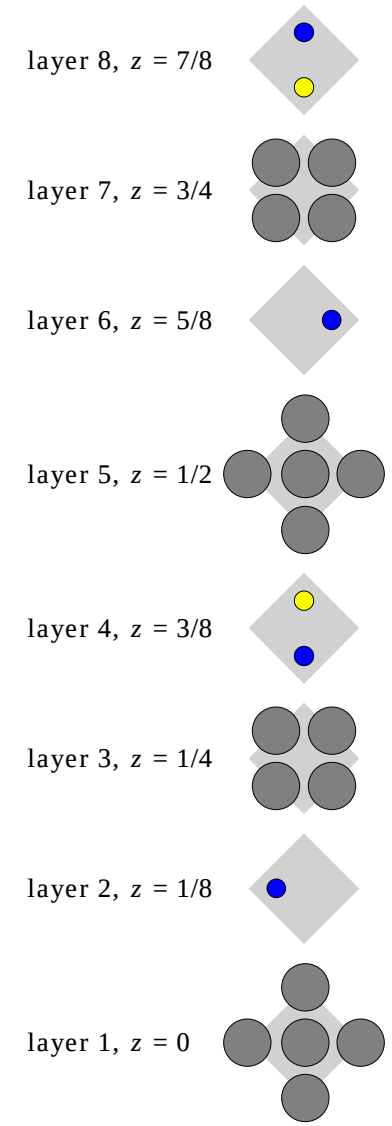


1, 3, 1' = colorless

2, 4 = blue

4, 8 = colored

Unit cell layers (quarter-size)

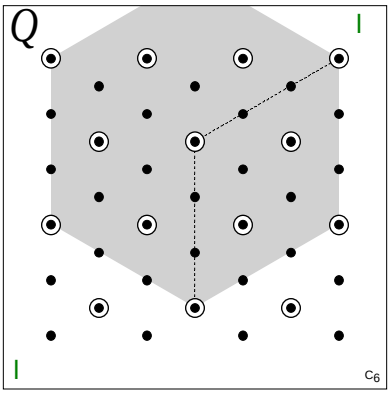


Graphite

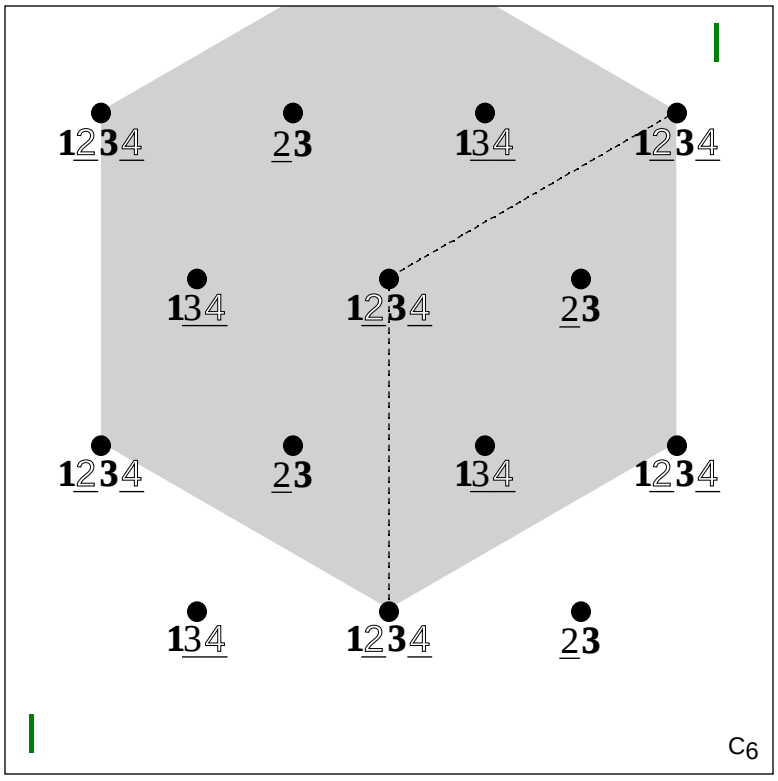
` To build the structure:

- Position the | on template *Q* in the same corner as the matching | on the base and align holes.
- Insert rods in the 14 circled holes.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

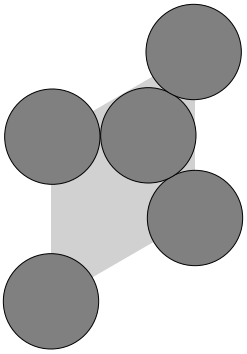
Template *Q* (half-size)



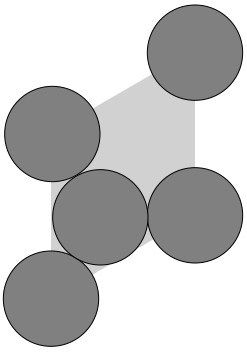
Pattern (actual size)



Unit cell layers (half-size)

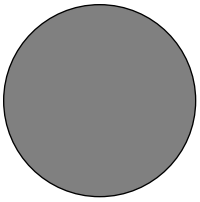


layer 3, *z* = 1/2



layer 1, *z* = 0

1, 3, 1' =



colorless

2, 4 =

2, 3 =

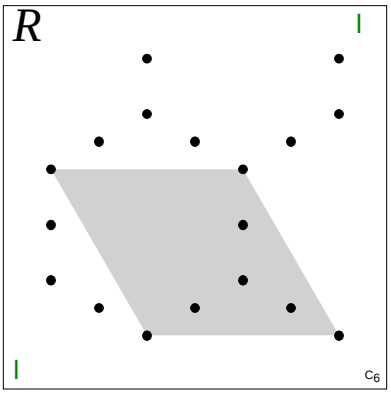
$H_2O(s)$

- The H atom positions should correspond to O–H···O but are built in this model as O··H··O.

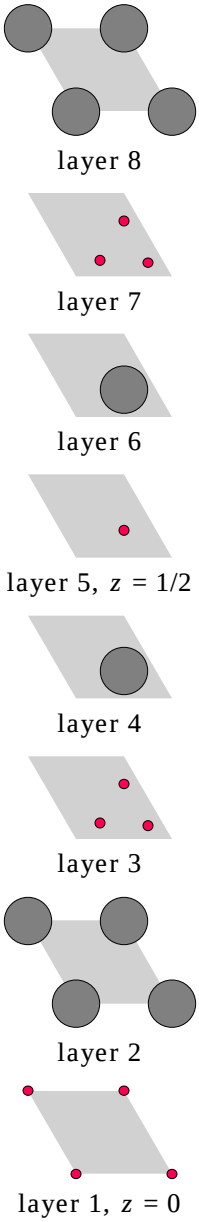
To build the structure:

- Position the | on template *R* in the same corner as the matching | on the base and align holes.
- Insert rods in all 18 holes.
- Build each layer in numerical order, 0 through 8, as described in the example directions. Finish each layer before starting the next layer.
- Spacer 5 is optional but adds to the stability of the structure.
- Complete the pattern by repeating the first layer (**1'**).
- When building the structure higher, repeat the layers in order.

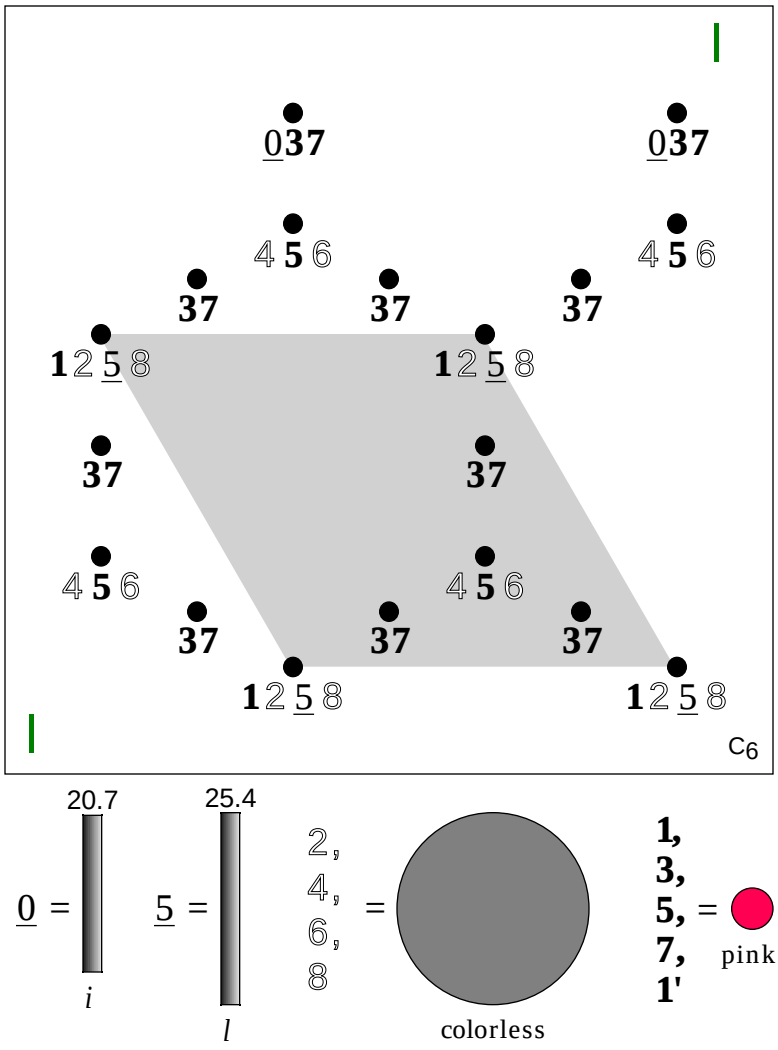
Template *R* (half-size)



Unit cell layers (half-size)



Pattern (actual size)



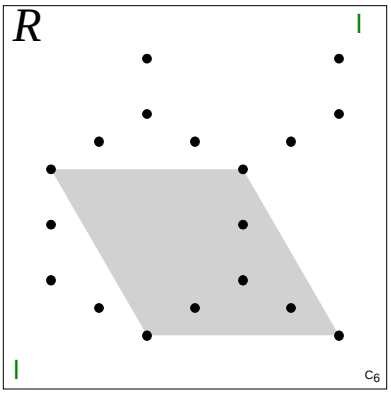
Silicates, SiO_3^{-2}, $Si_4O_{11}^{-6}$, $Si_2O_5^{-2}$

To build a silicate layer:

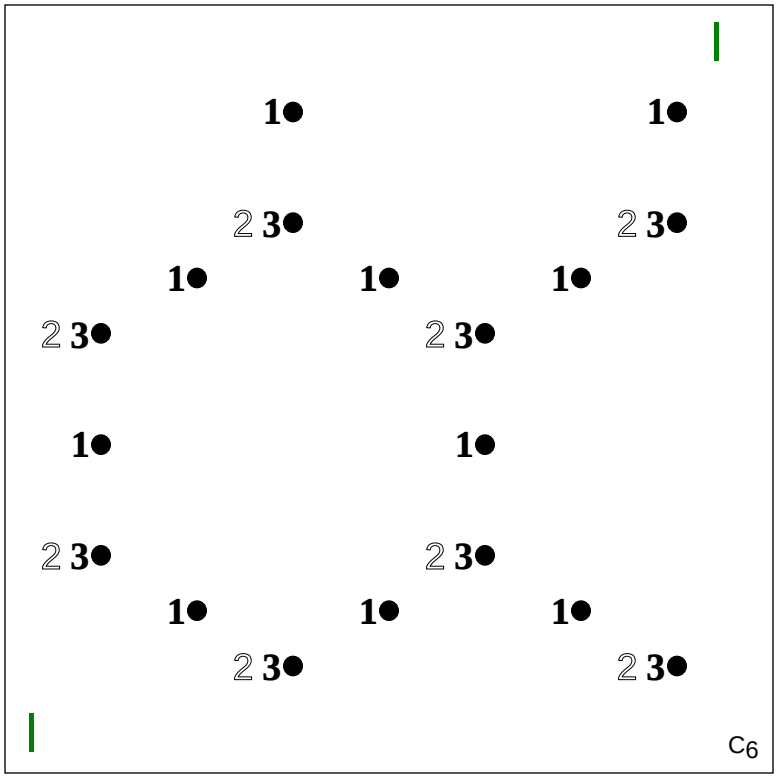
- Position the | on template *R* in the same corner as the matching | on the base and align holes.
- Insert rods in all 18 holes.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.

Note: In silicates, SiO_4^{-4} tetrahedra share one to four oxygen atoms with other tetrahedra. All other things being equal, the lower the temperature of formation, the higher the degree of polymerization: isolated SiO_4^{-4} (olivines), to single chains SiO_3^{-2} (pyroxenes), to double chains $Si_4O_{11}^{-6}$ (amphiboles), to sheets of $Si_2O_5^{-2}$ (micas). For charge balance other cations will be present in mineral structures. The portion of the structure that can be built on one model kit base is shown darker at the right. Layer 3 is directly on top of layer 2.

Template *R* (half-size)



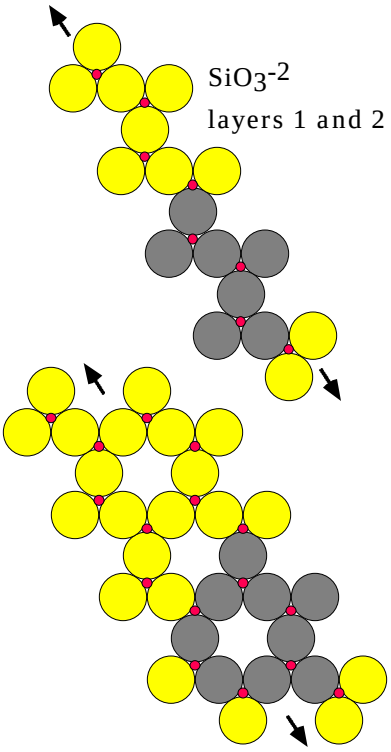
Pattern (actual size)



1, 3 = colorless

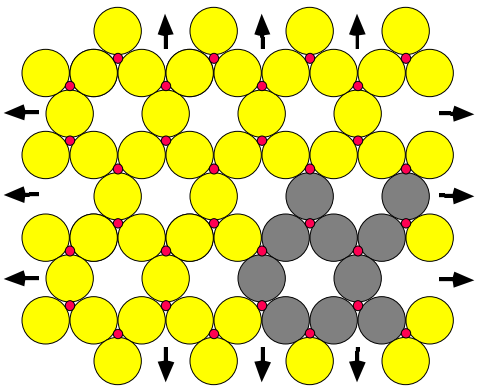
2 = pink

Structures (quarter-size)



SiO_3^{-2} layers 1 and 2

$Si_4O_{11}^{-6}$ layers 1 and 2



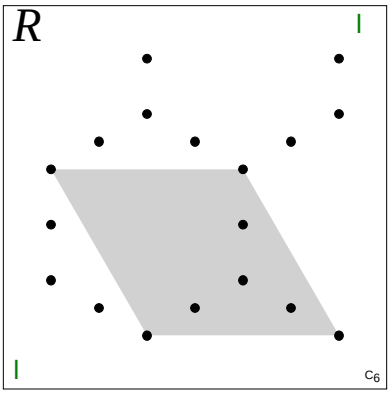
$Si_2O_5^{-2}$ layers 1and 2

Tridymite (Silica)

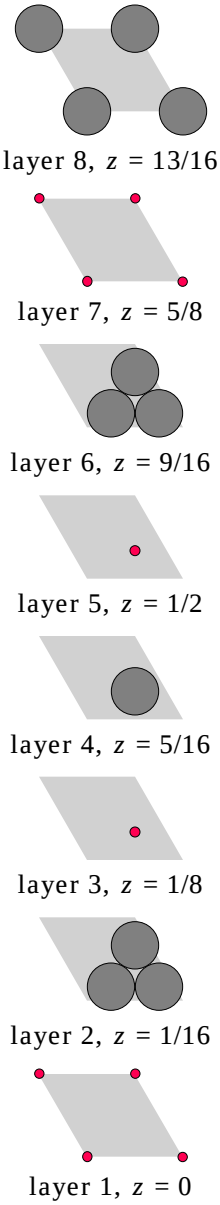
` To build the structure:

- Position the | on template *R* in the same corner as the matching | on the base and align holes.
- Insert rods in all 18 holes.
- Build each layer in numerical order, 0 through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).
- When building the structure higher, repeat the layers in order.

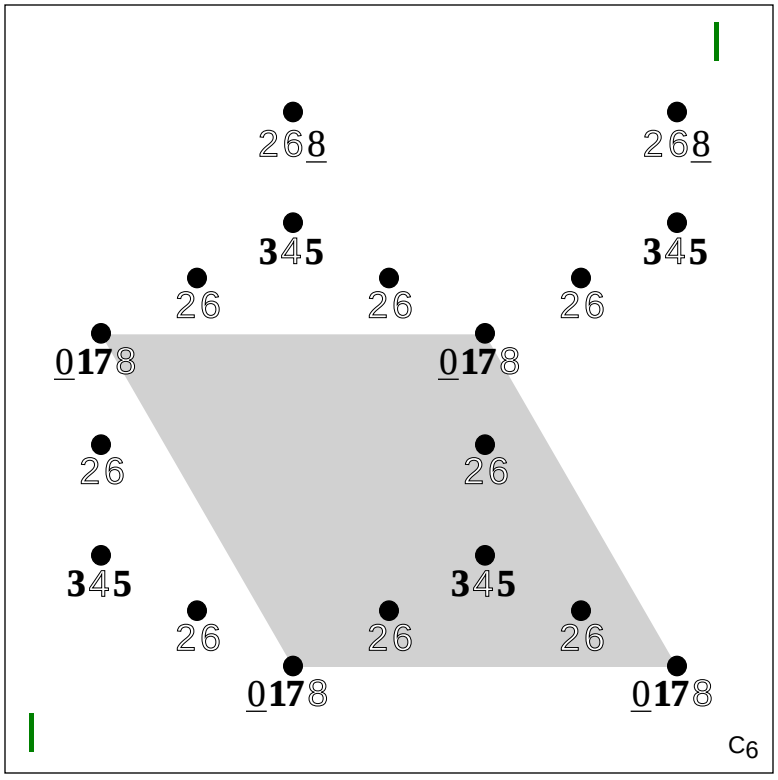
Template *R* (half-size)

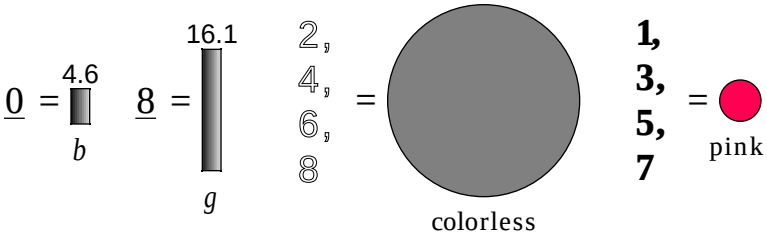


Unit cell layers (quarter-size)



Pattern (actual size)



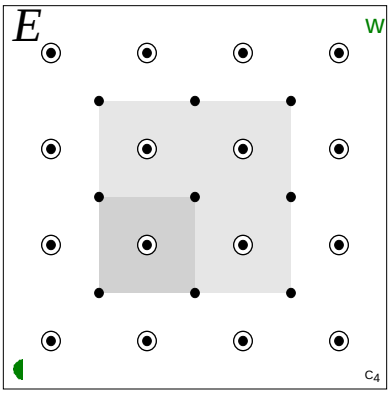


Cristobalite

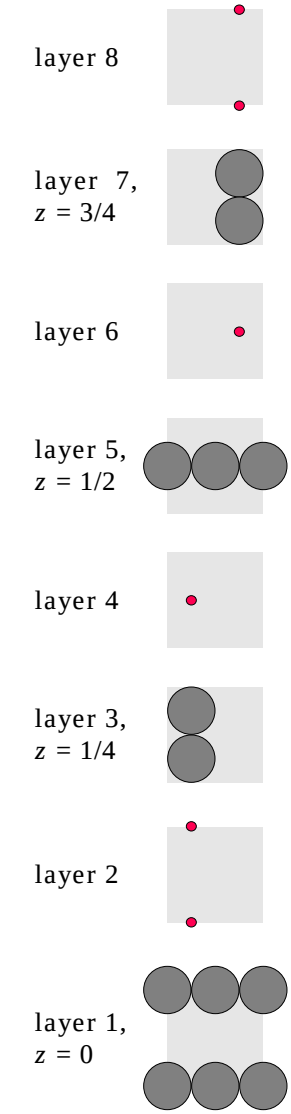
To build the structure:

- Position the won template E in the same corner as the matching won on the base and align holes.
- Insert rods in all 25 holes.
- Build layer 0 as described in the example directions. Build layer **1** next. Before placing layer 2 spheres, slide a row of layer **3** spheres down their rods. Put a layer 2 sphere on the tip of an extra rod, tilt the model, lift a layer **3** sphere, and use the rod as a pointer to place the layer 2 sphere as shown below. Remove the pointer.
- Coontinue building the odd numbered layers in numerical order, placing the even numbered spheres as above. Finish each pair of layers before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).
- When building the structure higher, repeat the layers in order.

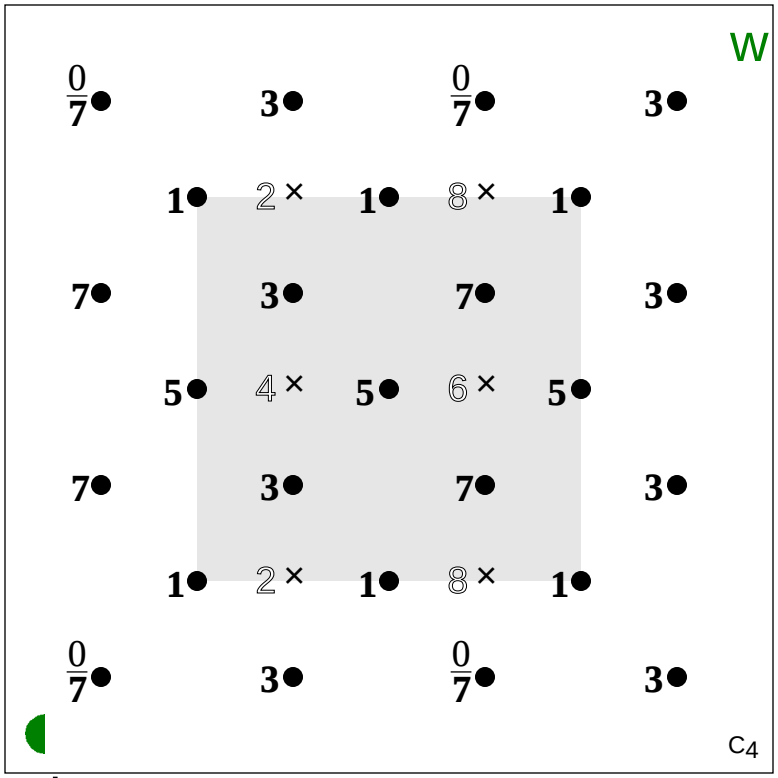
Template E (half-size)



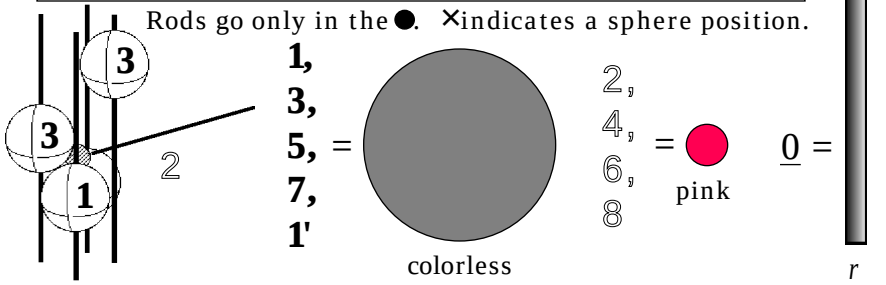
Unit cell layers (quarter-size)



Pattern (actual size)



Rods go only in the ●. ×indicates a sphere position.



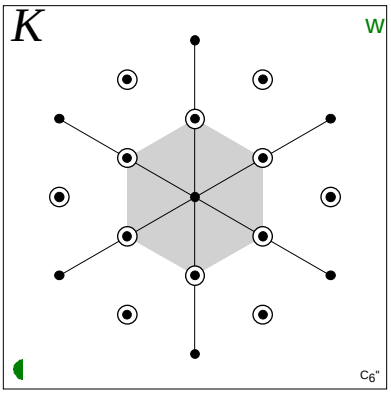
Quartz, SiO_2

- Note: only the silicon atoms are shown. Oxygen atoms bridge between adjacent pairs of silicon atoms, with a Si-O-Si bond angle of 143.6°.

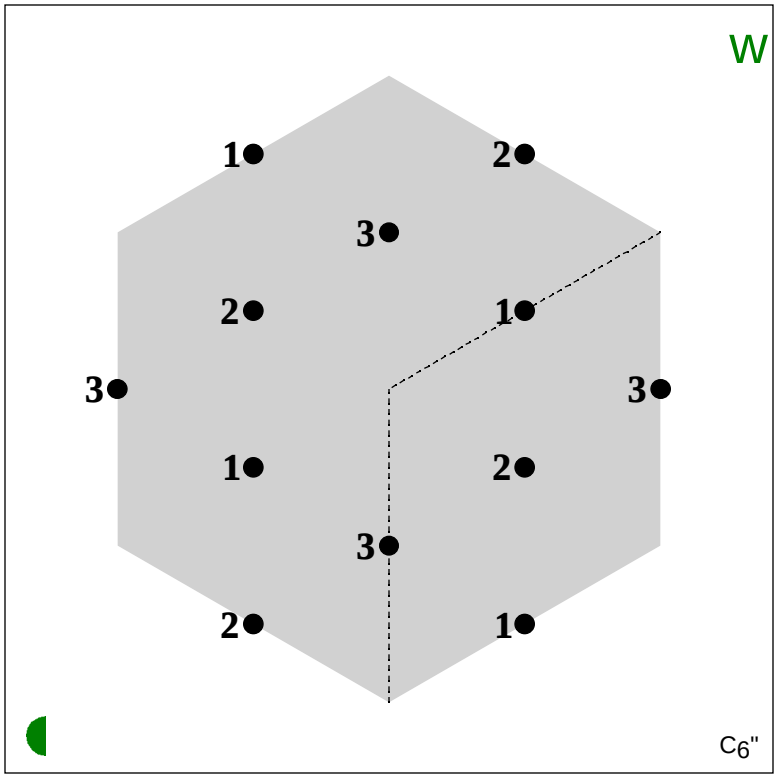
To build the structure:

- Position the w on template *K* in the same corner as the matching w on the base and align holes.
- Insert rods in the 12 circled holes.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).
- When building the structure higher, repeat the layers in order.

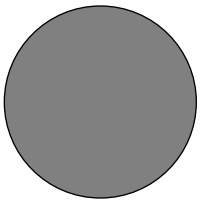
Template *K* (half-size)



Pattern (actual size)

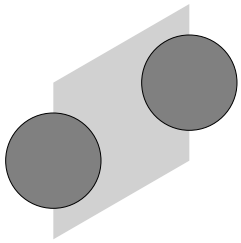


1, 2, 3, 1' =

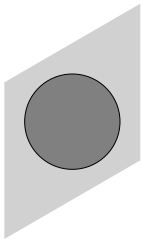


colorless

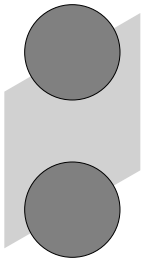
Unit cell layers (half-size)



layer 3, *z* = 2/3



layer 2, *z* = 1/3



layer 1, *z* = 0

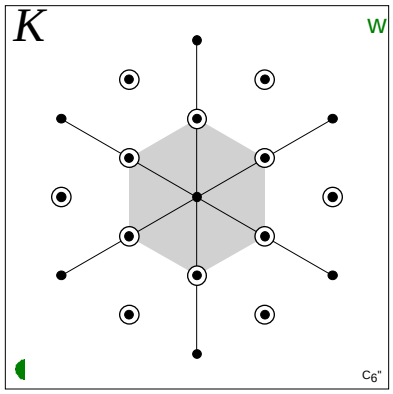
Quartz, SiO_2 (alternate)

- Note: only the silicon atoms are shown. Oxygen atoms bridge between adjacent pairs of silicon atoms, with a Si-O-Si bond angle of 143.6°.

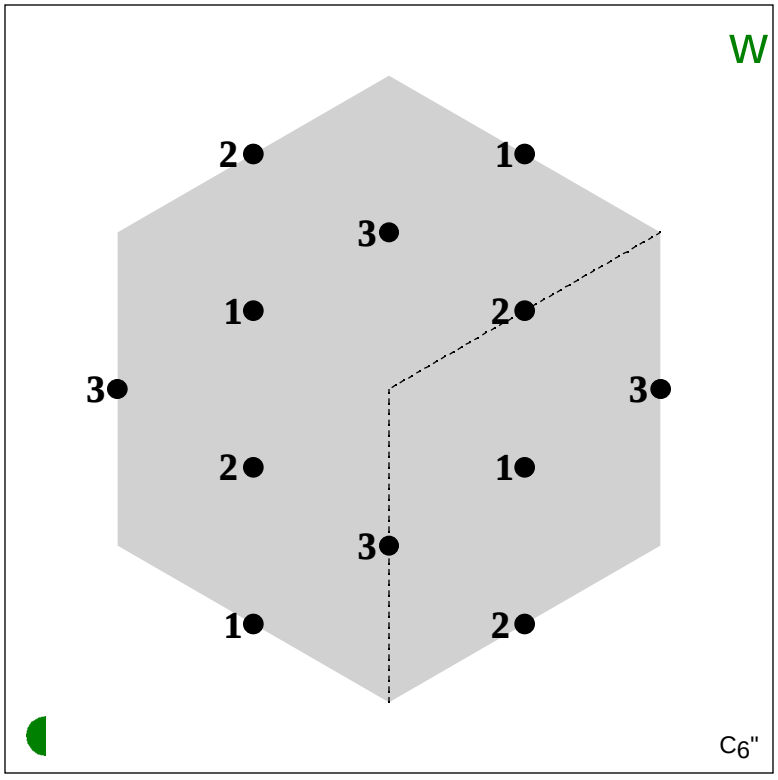
To build the structure:

- Position the won template *K* in the same corner as the matching won the base and align holes.
- Insert rods in the 12 circled holes.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).
- When building the structure higher, repeat the layers in order.

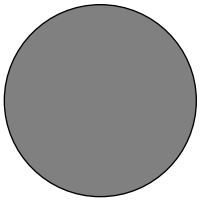
Template *K* (half-size)



Pattern (actual size)

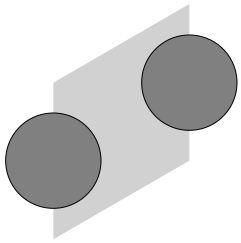


1, 2, 3, 1' =

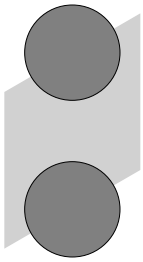


colorless

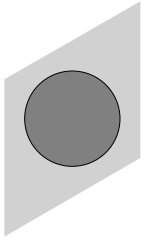
Unit cell layers (half-size)



layer 3, *z* = 2/3



layer 2, *z* = 1/3



layer 1, *z* = 0

Rutile (tetragonal)

- In rutile type structures, the positions of the larger spheres are distorted from the positions used here (for example, .3, .3, 0 in TiO_2 instead of .25, .25, 0 in this model).

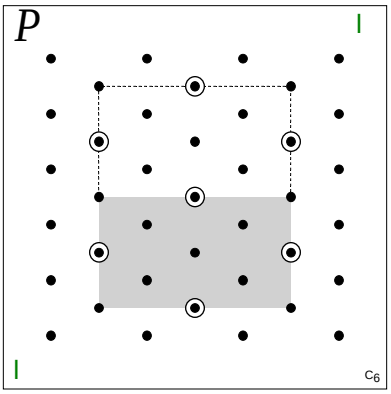
To build a unit cell:

- Position the | on template *P* in the same corner as the matching | on the base and align holes.
- Insert rods in 9 uncircled holes in the shaded region.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

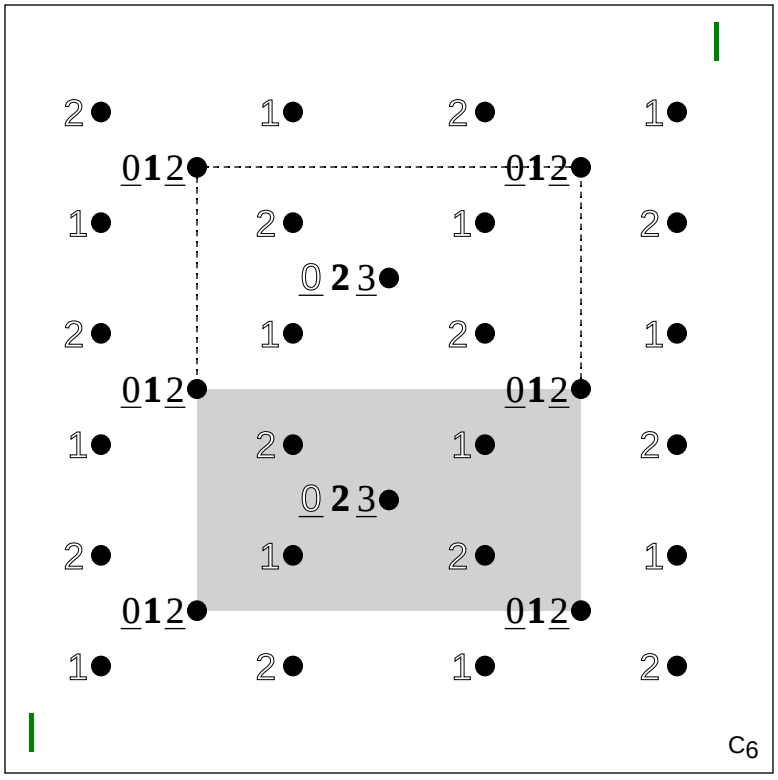
To build more than a unit cell:

- Place rods in additional uncircled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

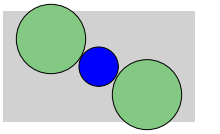
Template *P* (half-size)



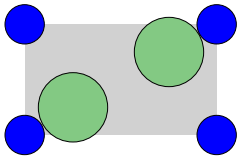
Pattern (actual size)



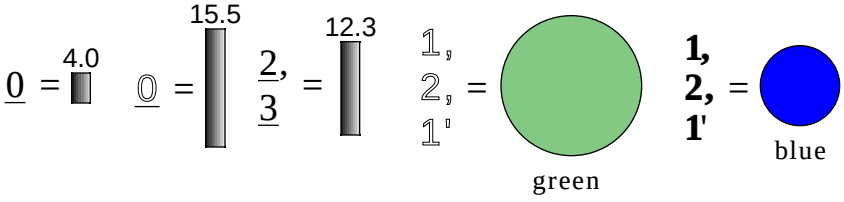
Unit cell layers (half-size)



layer 2, *z* = 1/2



layer 1, *z* = 0



Molybdenite, MoS_2

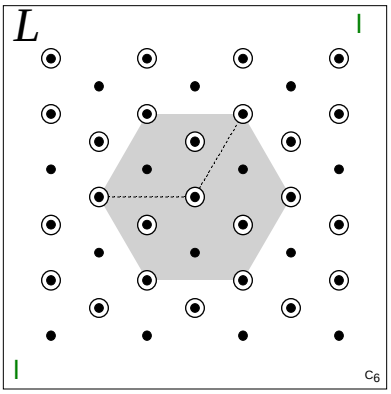
To build a hexagonal section:

- Position the | on template L in the same corner as the matching | on the base and align holes.
- Insert rods in the 10 circled holes in the shaded region.
- Build each layer in numerical order, **1** through 6, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

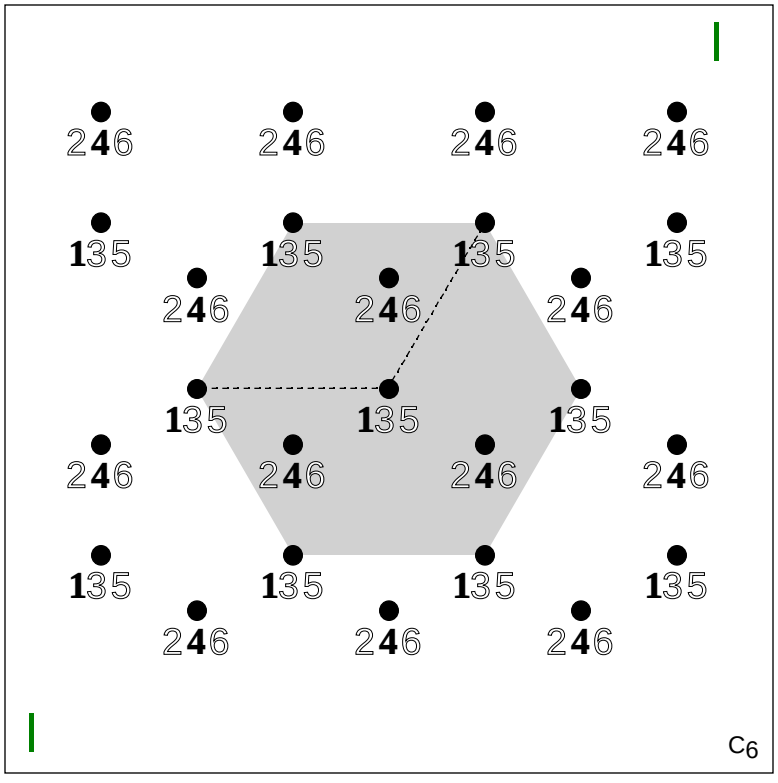
To build more than a hexagonal section:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

Template L (half-size)



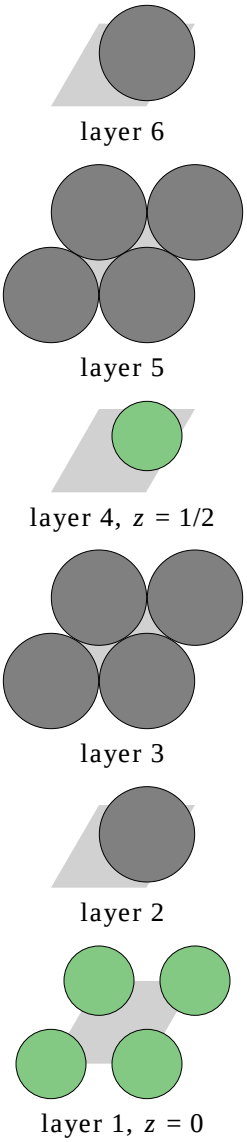
Pattern (actual size)



2, 3, 5, 6 = colorless

1, 4, 1' = green

Unit cell layers (half-size)



GaSe

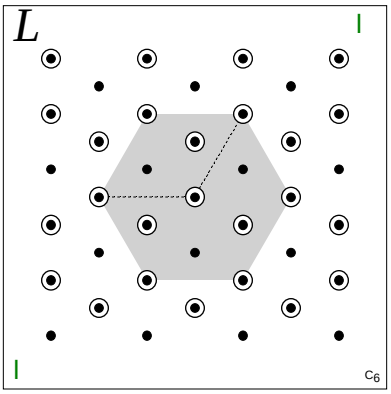
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in the 10 circled holes in the shaded region.
- Build each layer in numerical order, **1** through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

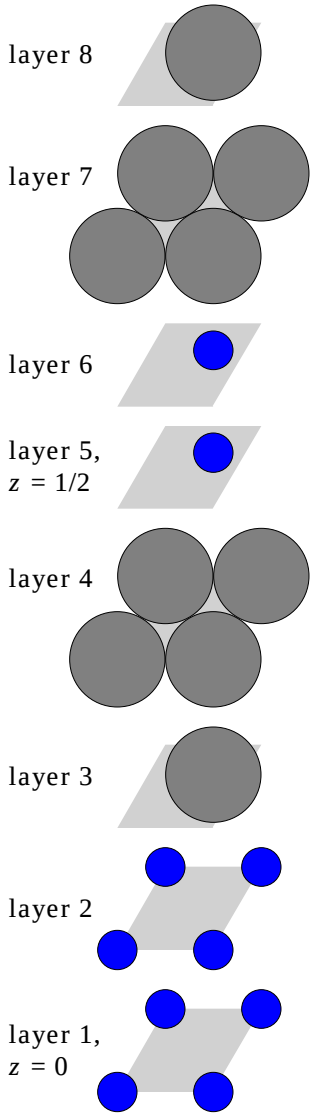
To build more than a hexagonal section:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

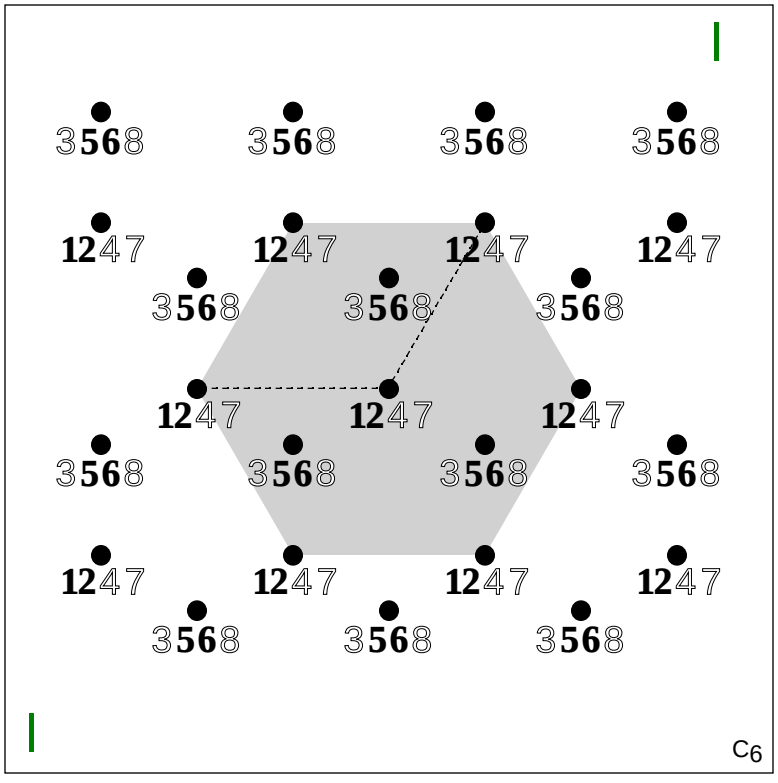
Template *L* (half-size)

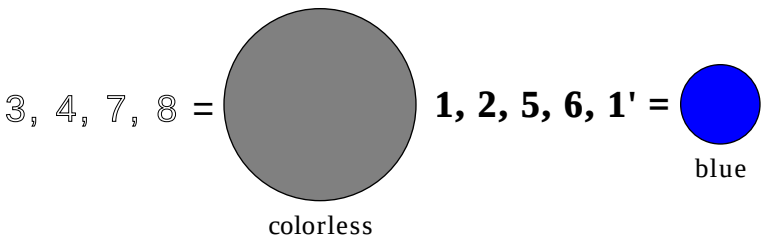


Unit cell layers (half-size)



Pattern (actual size)





Li_3N

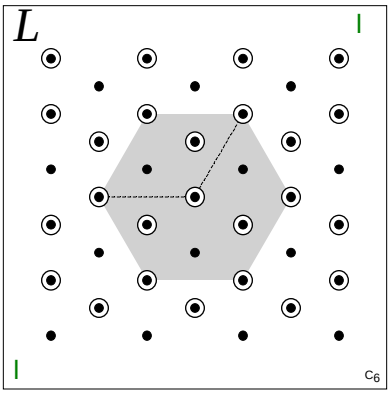
To build a unit cell:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in 6 holes in the parallelogram region.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1',**1').

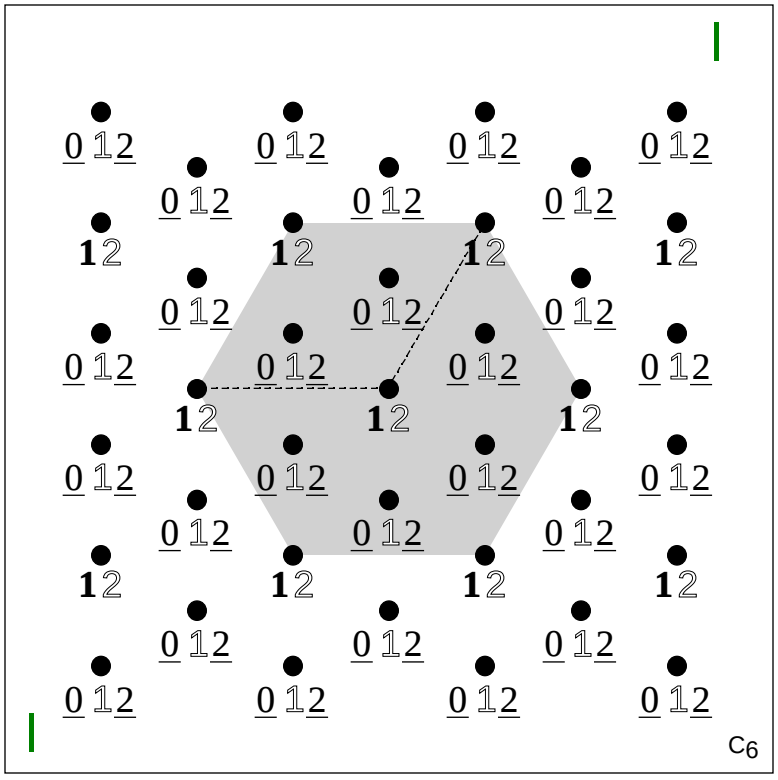
To build more than a unit cell:

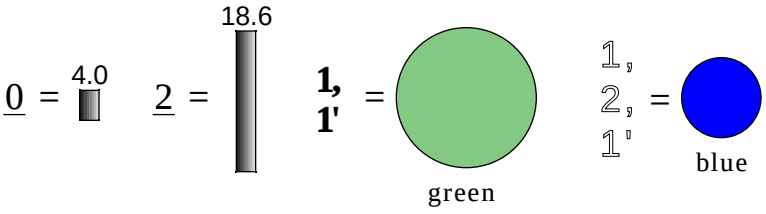
- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

Template *L* (half-size)

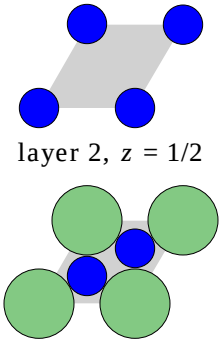


Pattern (actual size)





Unit cell layers (half-size)



$LiNbO_2$

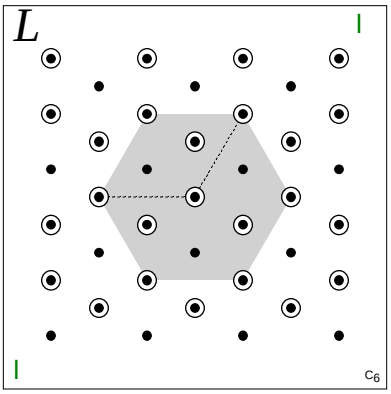
To build a hexagonal section:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

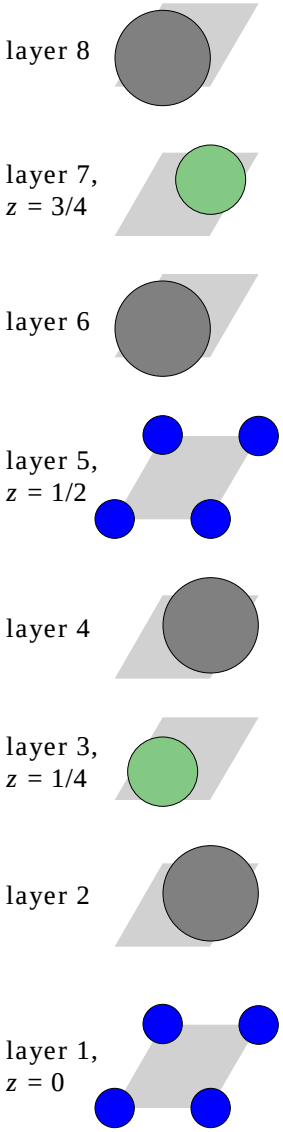
To build more than a hexagonal section:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

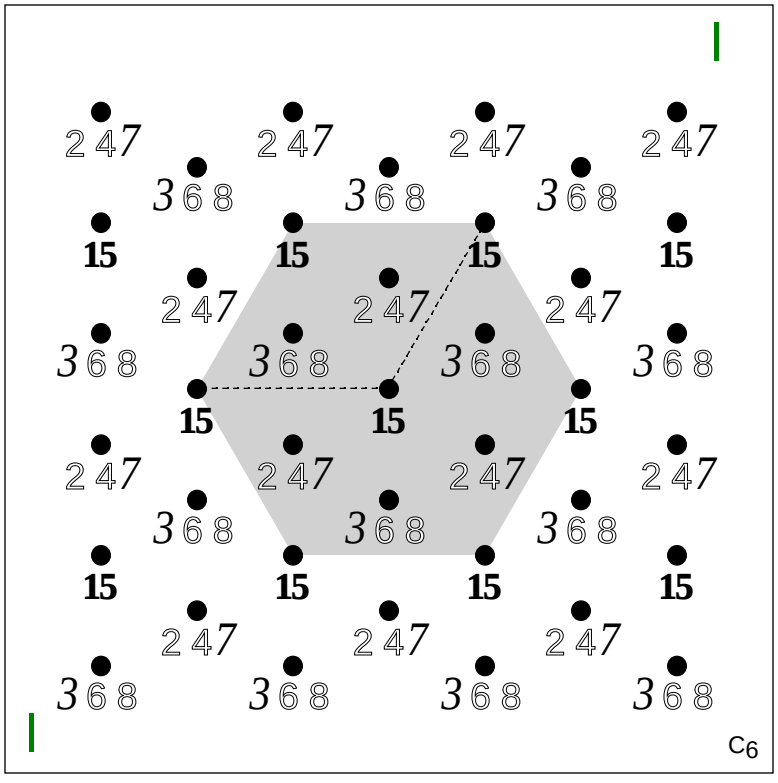
Template *L* (half-size)

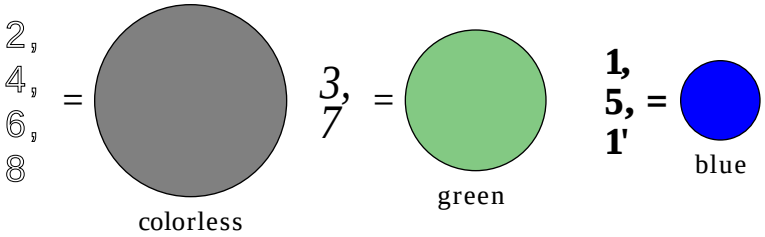


Unit cell layers (half-size)



Pattern (actual size)





Cu_2Sb (tetragonal)

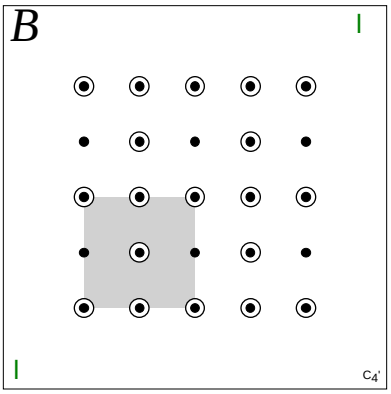
To build a unit cell:

- Position the | on template *B* in the same corner as the matching | on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, **1** through **5**, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

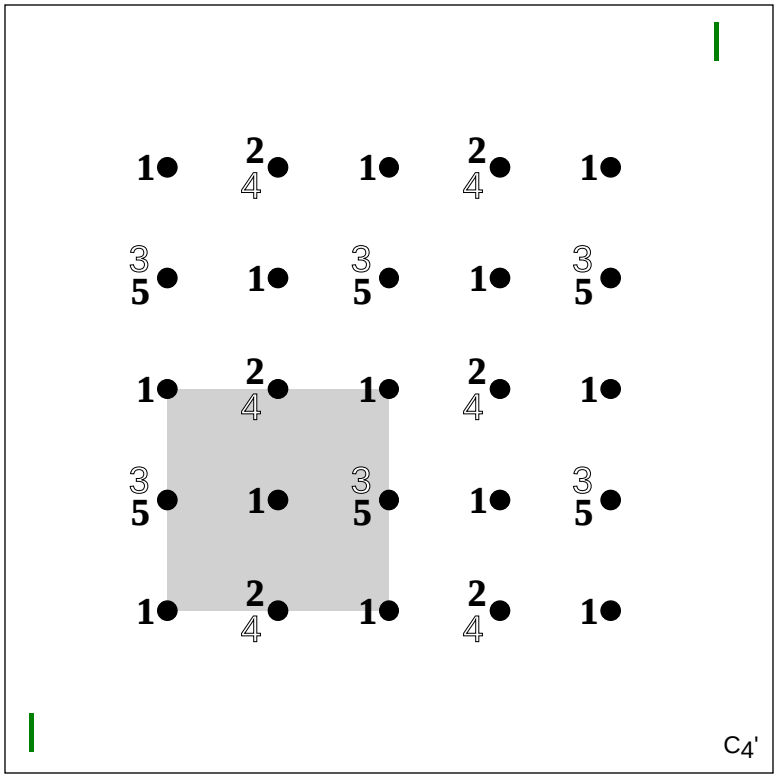
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

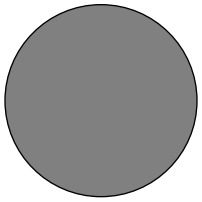
Template *B* (half-size)



Pattern (actual size)

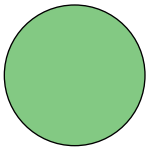


3, 4 =



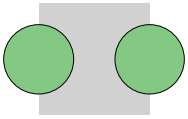
colorless

1, 2, 5, 1' =

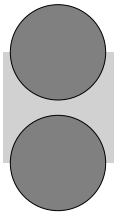


green

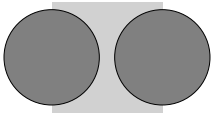
Unit cell layers (half-size)



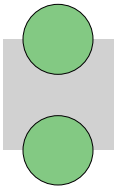
layer 5



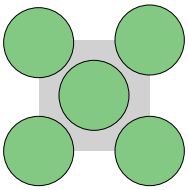
layer 4



layer 3



layer 2



layer 1

PbO (tetragonal)

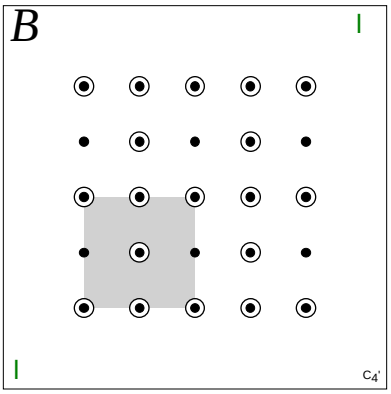
To build a unit cell:

- Position the | on template *B* in the same corner as the matching | on the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, **1** through 3, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

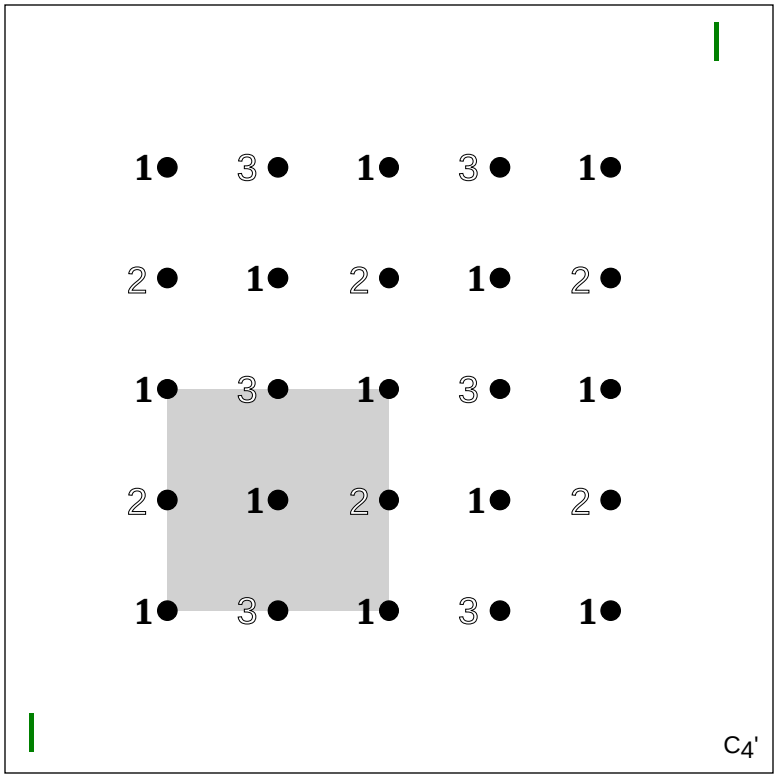
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

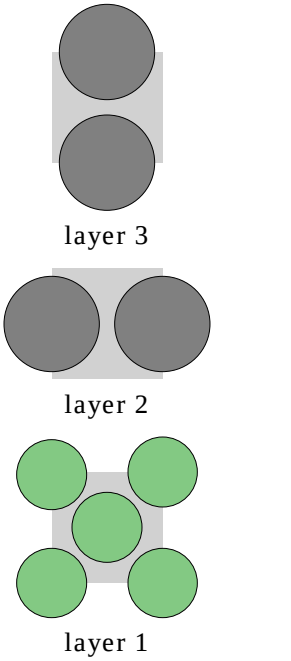
Template *B* (half-size)



Pattern (actual size)



Unit cell layers (half-size)



2, 3 = colorless

1, 1' = green

PtS (tetragonal)

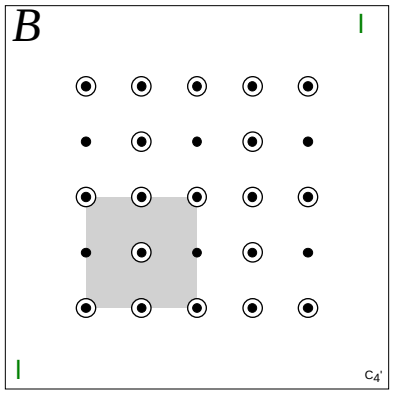
To build a unit cell:

- Position the | on template *B* in the same corner as the matching | on the base and align holes.
- Insert rods in the 7 circled holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

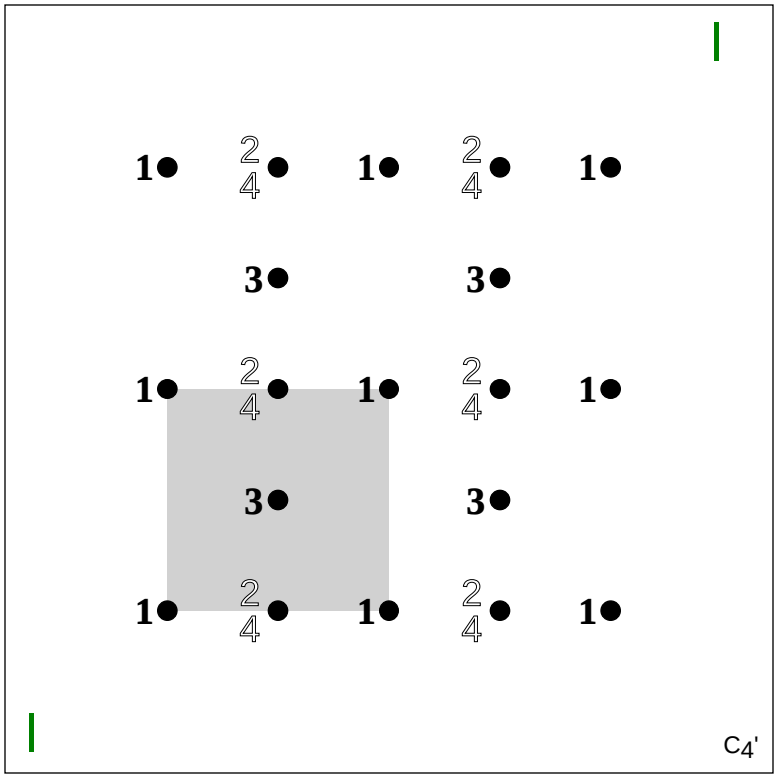
To build more than a unit cell:

- Place rods in additional circled holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

Template *B* (half-size)



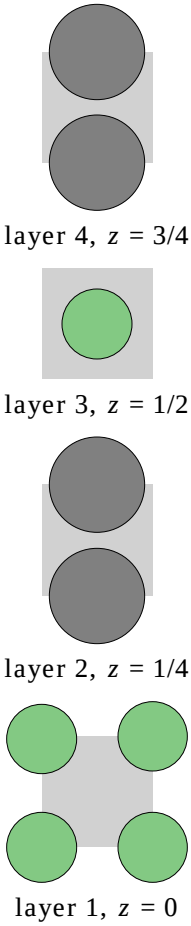
Pattern (actual size)



2, 4 = colorless

1, 3, 1' = green

Unit cell layers (half-size)



layer 4, *z* = 3/4

layer 3, *z* = 1/2

layer 2, *z* = 1/4

layer 1, *z* = 0

PtS (alternate tetragonal)

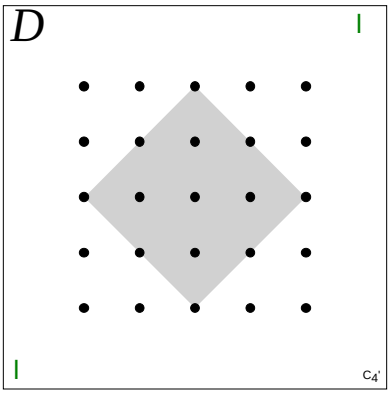
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in 9 holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

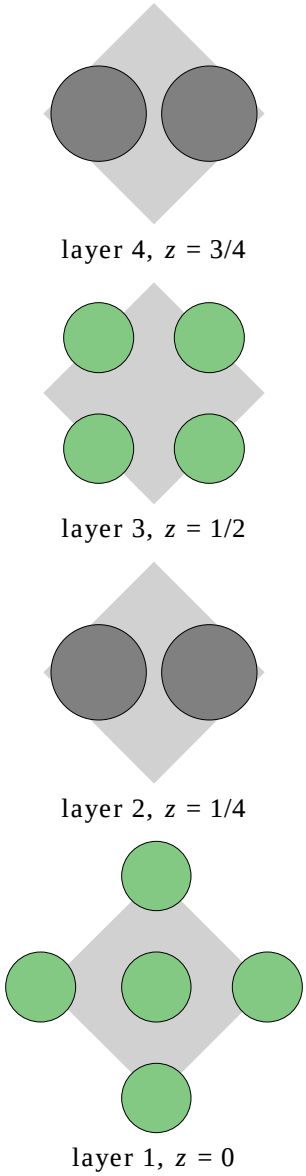
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

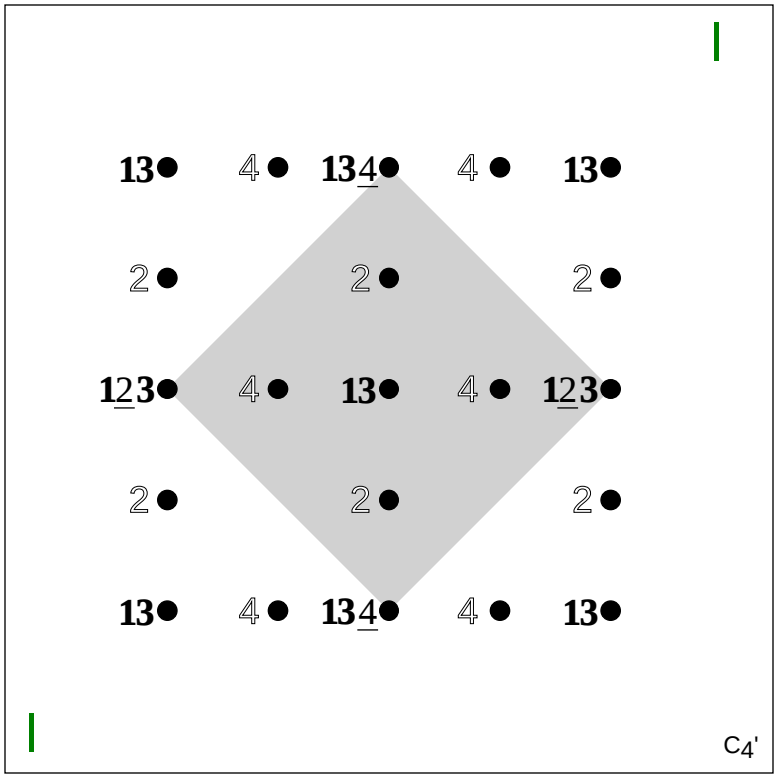
Template *D* (half-size)

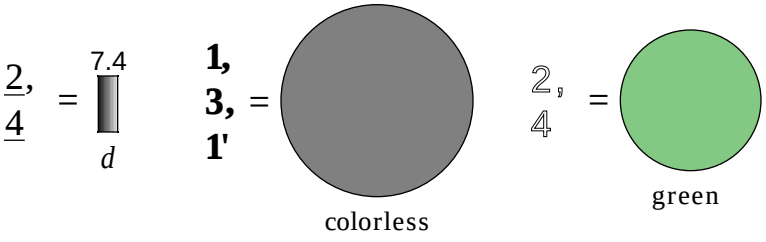


Unit cell layers (half-size)



Pattern (actual size)





Cu_2O

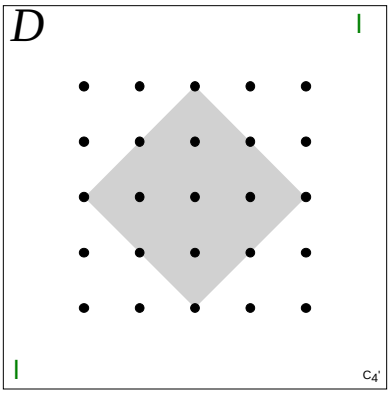
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in 9 holes in the shaded region.
- Build each layer in numerical order, **1** through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

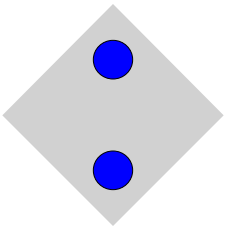
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above. The spacers are required only if you build just the shaded area.
- When building the structure higher, repeat the layers in order.

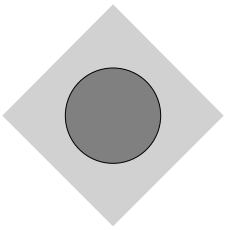
Template *D* (half-size)



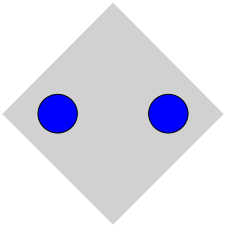
Unit cell layers (half-size)



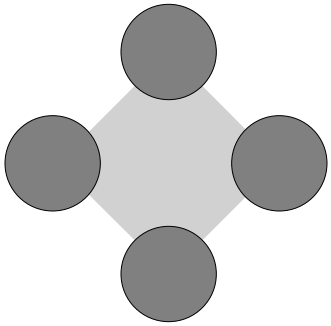
layer 4, *z* = 3/4



layer 3, *z* = 1/2

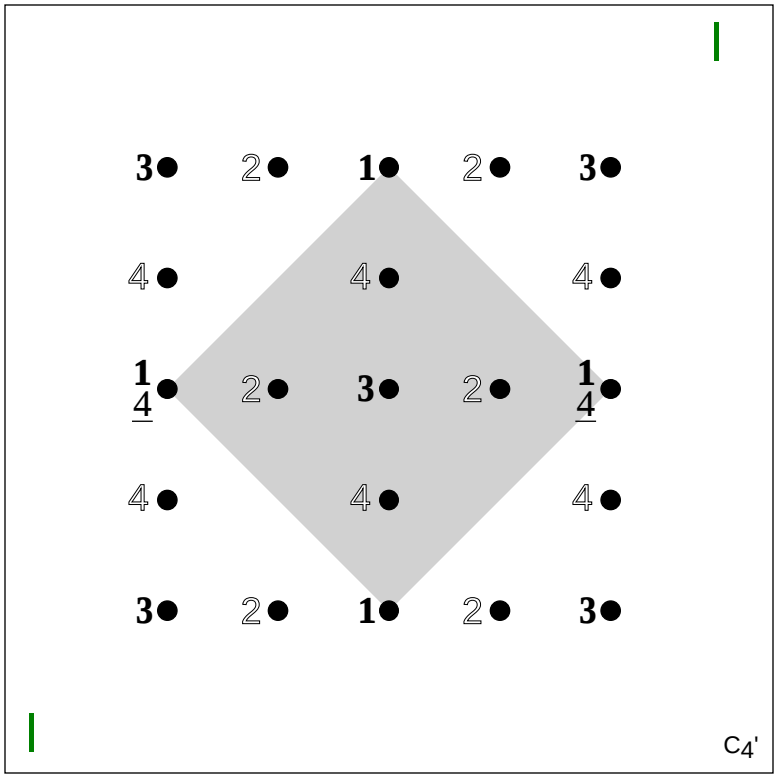


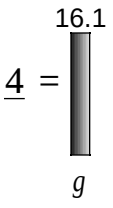
layer 2, *z* = 1/4

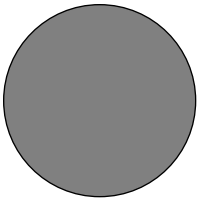


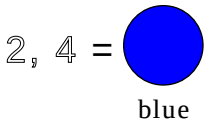
layer 1, *z* = 0

Pattern (actual size)









Cu_2O (alternate)

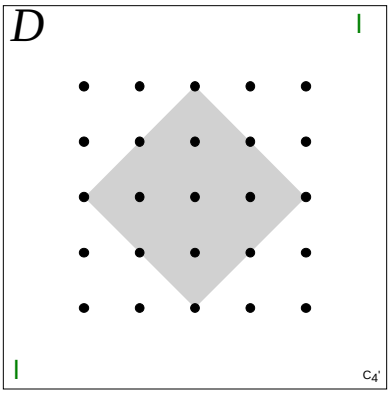
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in 11 holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

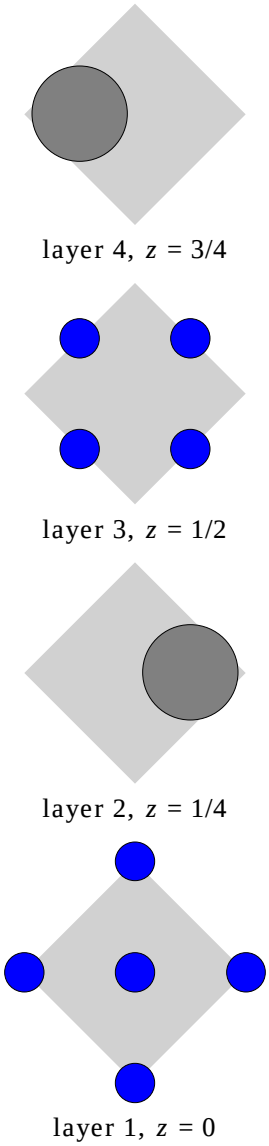
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

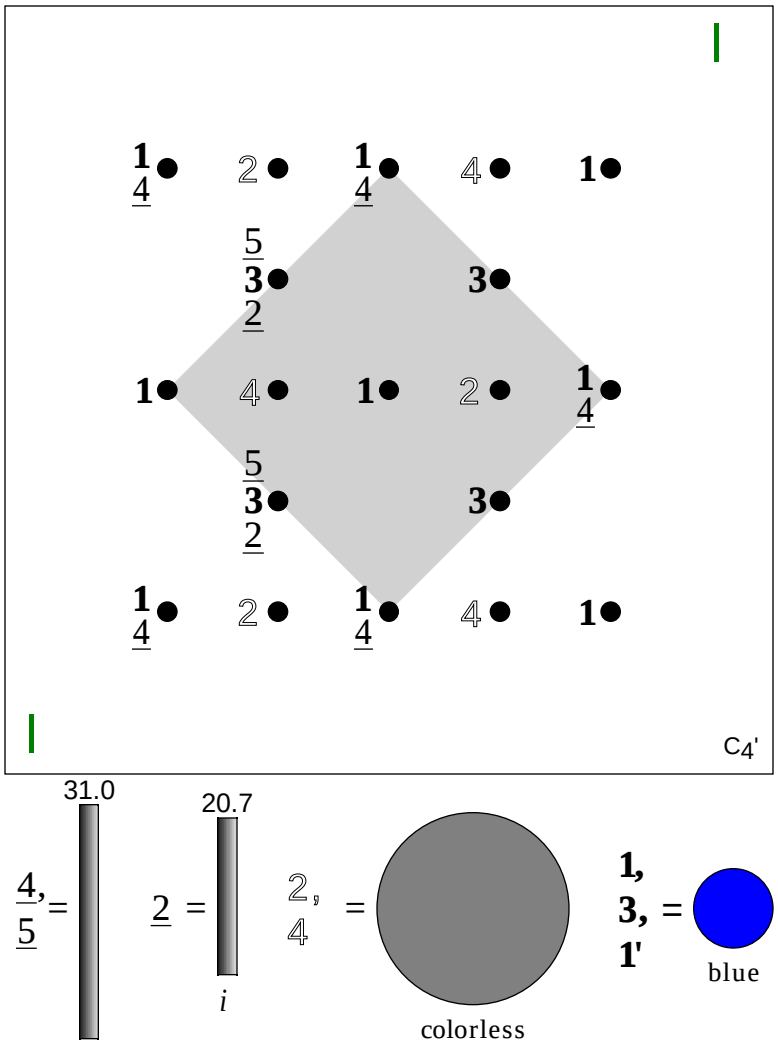
Template *D* (half-size)



Unit cell layers (half-size)



Pattern (actual size)



CaC_2

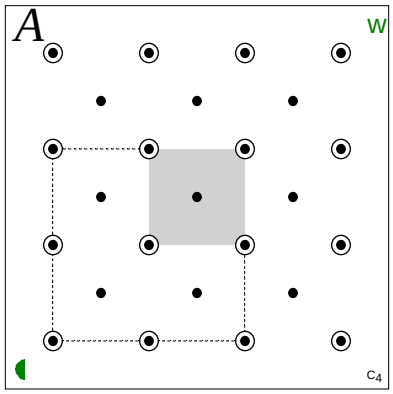
To build a unit cell:

- Position the won template *A* in the same corner as the matching won the base and align holes.
- Insert rods in all 5 holes in the shaded region.
- Build each layer in numerical order, 0 through 6, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

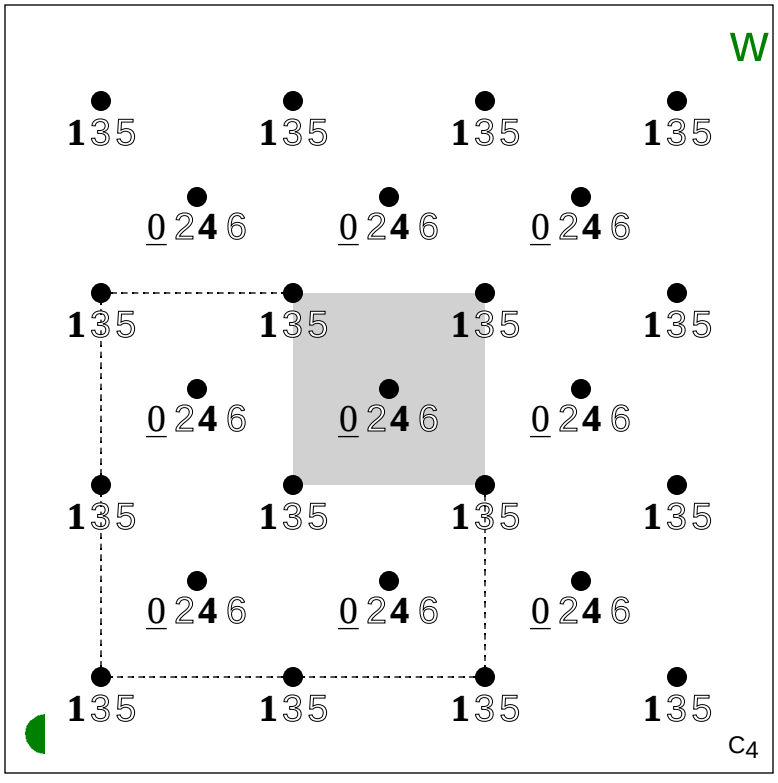
To build more than a unit cell:

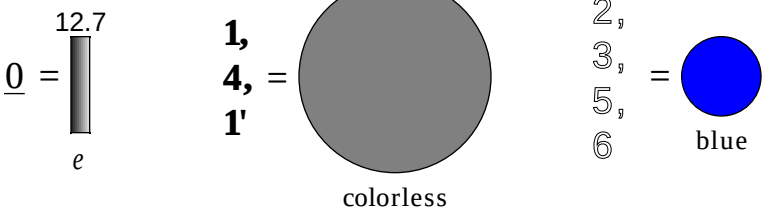
- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

Template *A* (half-size)

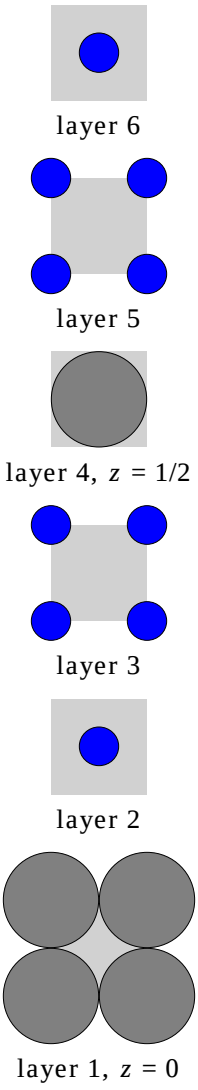


Pattern (actual size)





Unit cell layers (half-size)



XeF_2

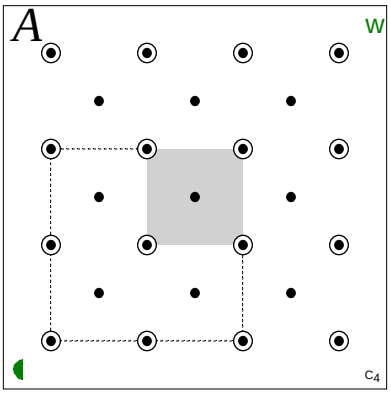
To build a unit cell:

- Position the won template *A* in the same corner as the matching won on the base and align holes.
- Insert rods in 5 holes in the dash-enclosed region.
- Build each layer in numerical order, **1** through 7, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

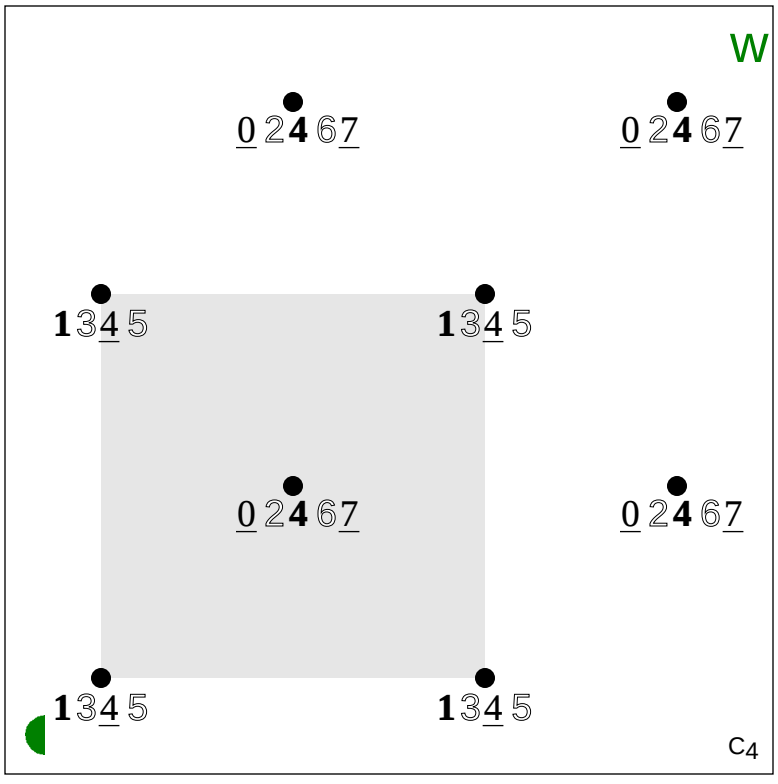
To build more than a unit cell:

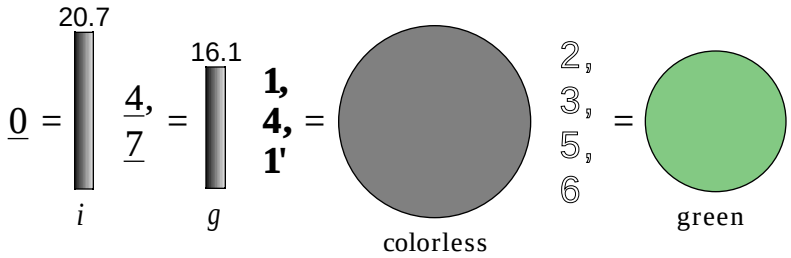
- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

Template *A* (half-size)

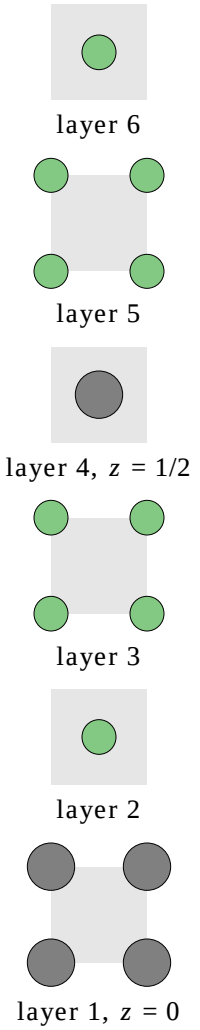


Pattern (actual size)





Unit cell layers (quarter-size)



$MoSi_2$

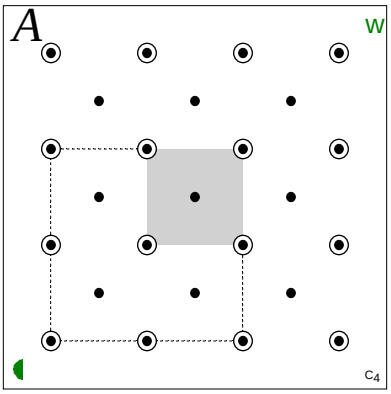
To build a unit cell:

- Position the won template *A* in the same corner as the matching won the base and align holes.
- Insert rods in all 5 holes in the shaded region.
- Build each layer in numerical order, **1** through 6, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

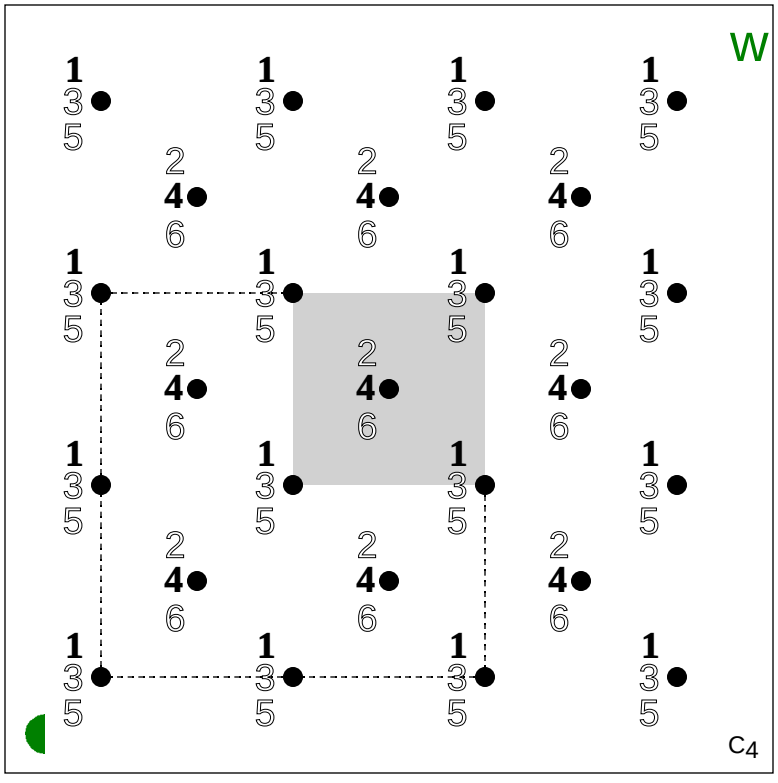
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

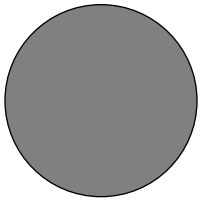
Template *A* (half-size)



Pattern (actual size)

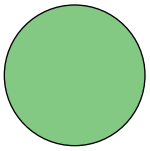


2, 3, 5, 6 =



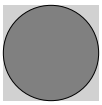
colorless

1, 4, 1' =

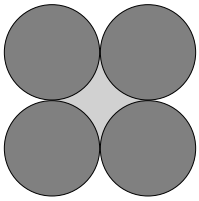


green

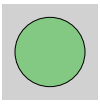
Unit cell layers (half-size)



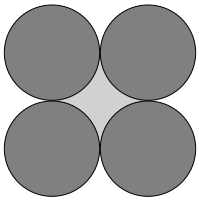
layer 6



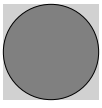
layer 5



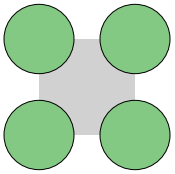
layer 4, *z* = 1/2



layer 3



layer 2



layer 1, *z* = 0

Hg_2Cl_2

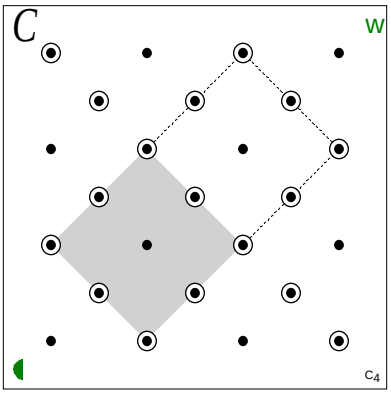
To build a unit cell:

- Position the won template *C* in the same corner as the matching won the base and align holes.
- Insert rods in 5 holes in the shaded region.
- Build each layer in numerical order, 0 through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

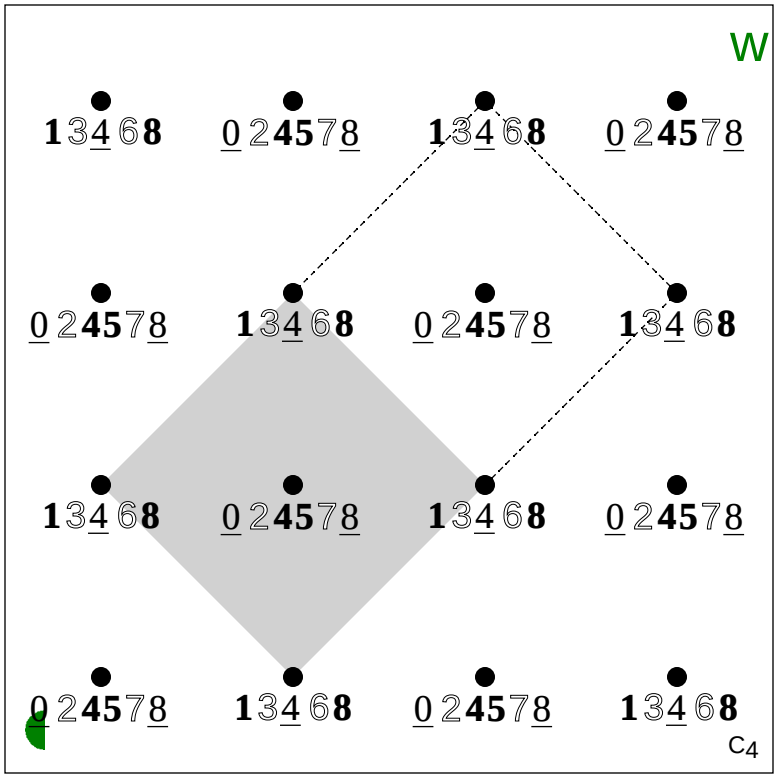
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

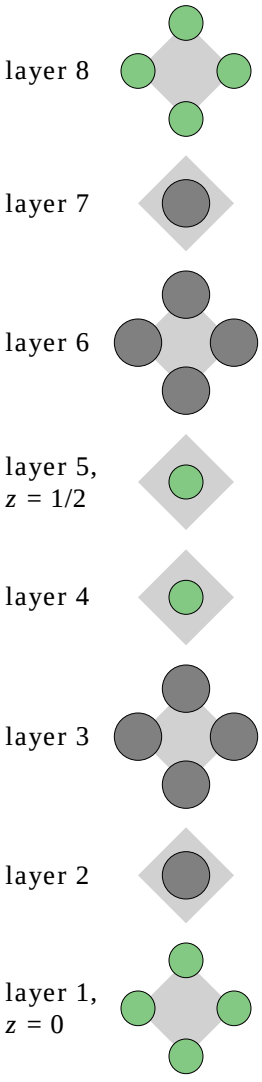
Template *C* (half-size)



Pattern (actual size)



Unit cell layers (quarter-size)



0 = 2.9 4, 8 = 5.9 2, 3, 6, 7 = colorless 1, 4, 5, 8, 1' = green

$ThCr_2Si_2$

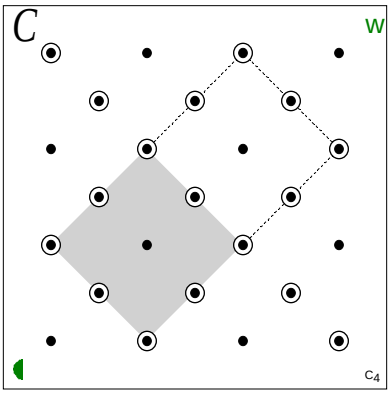
To build a unit cell:

- Position the won template *C* in the same corner as the matching won the base and align holes.
- Insert rods in all 9 holes in the shaded region.
- Build each layer in numerical order, 0 through 8, as described in the example directions. Finish each layer before starting the next layer.
- Complete the unit cell by repeating the first layer (**1'**).

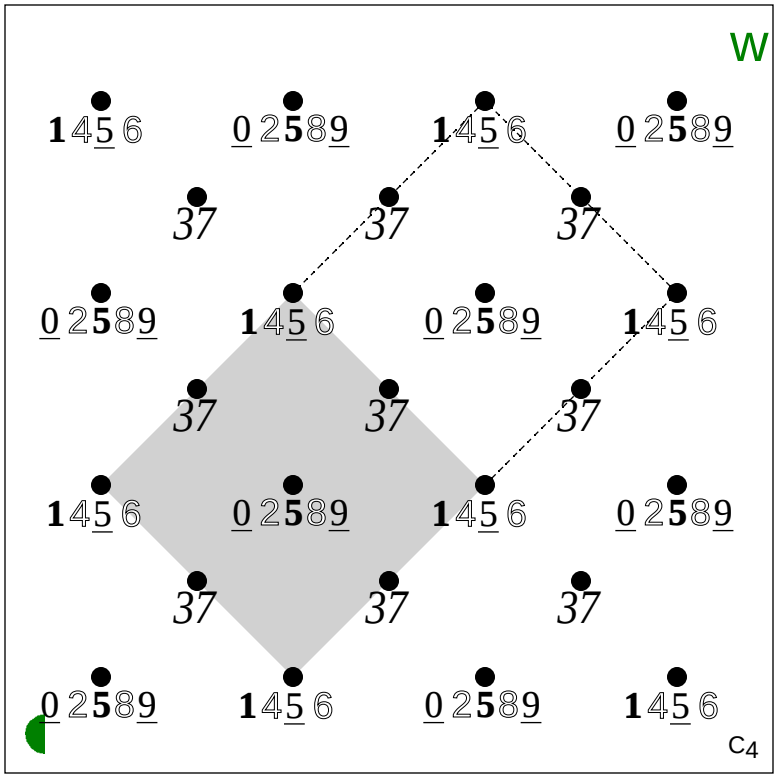
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order, omitting spacer 0.

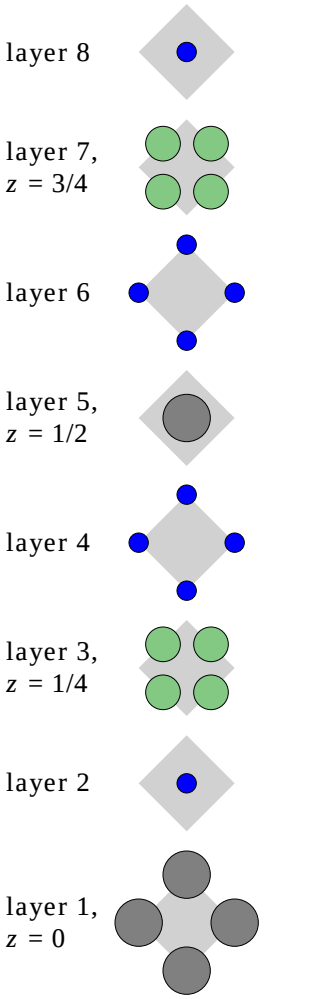
Template *C* (half-size)

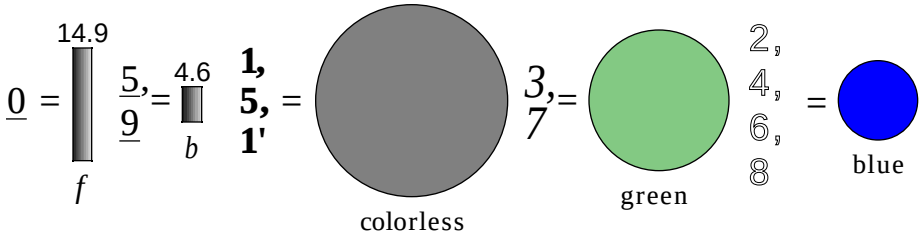


Pattern (actual size)



Unit cell layers (quarter-size)





NiTi (low temperature martensite phase)

- This model uses two different colors of large spheres.

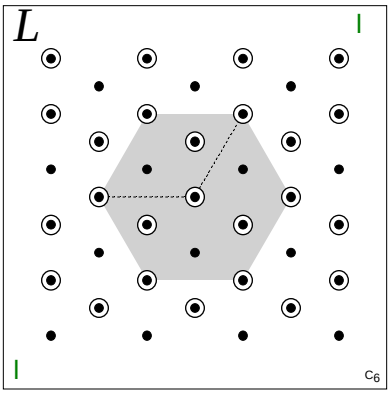
To build a unit cell:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.
- Insert rods in the 7 indicated holes.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**,1').

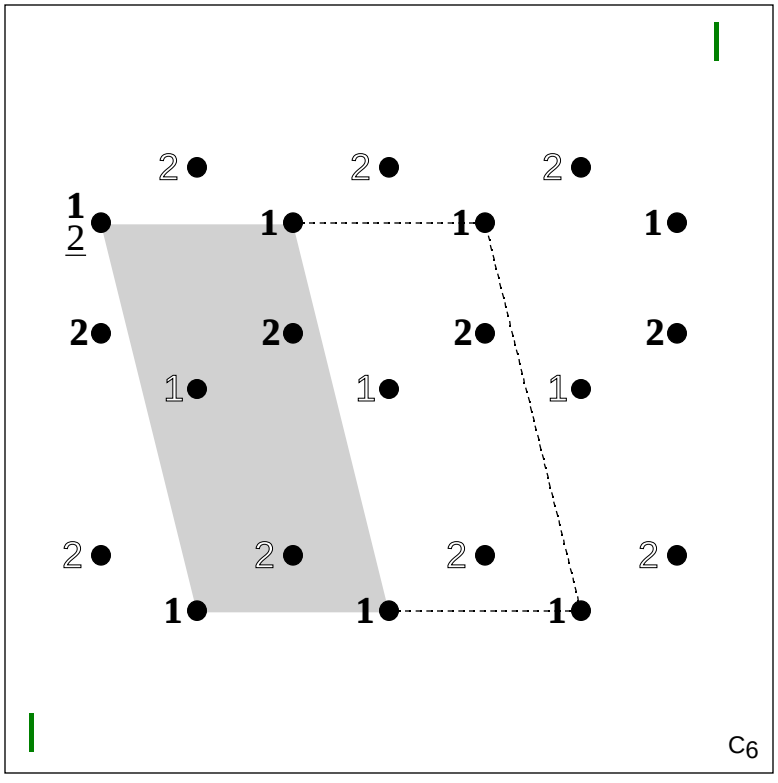
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

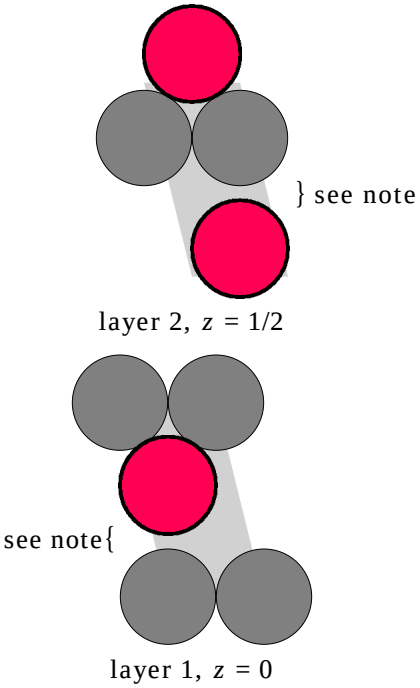
Template *L* (half-size)



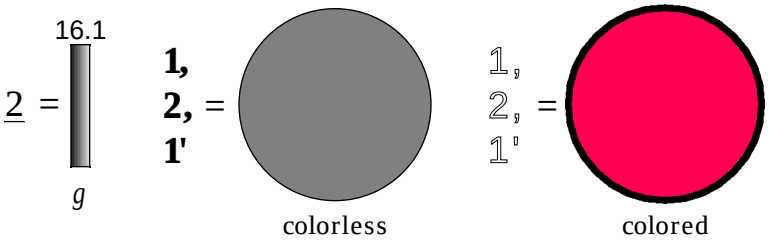
Pattern (actual size)



Unit cell layers (half-size)



Note: The longest dimension of the unit cell is longer in this model than in NiTi. The spheres should touch at the {.



NiTi (high temperature phase)

- This model uses two different colors of large spheres.

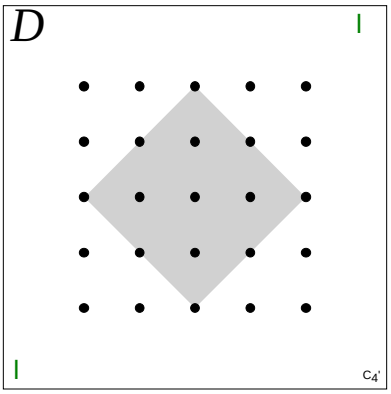
To build a unit cell:

- Position the | on template *D* in the same corner as the matching | on the base and align holes.
- Insert rods in 9 holes in the shaded region.
- Build each layer in numerical order, **1** through 2, as described in the example directions. Finish each layer before starting the next layer.
- Complete the pattern by repeating the first layer (**1'**).

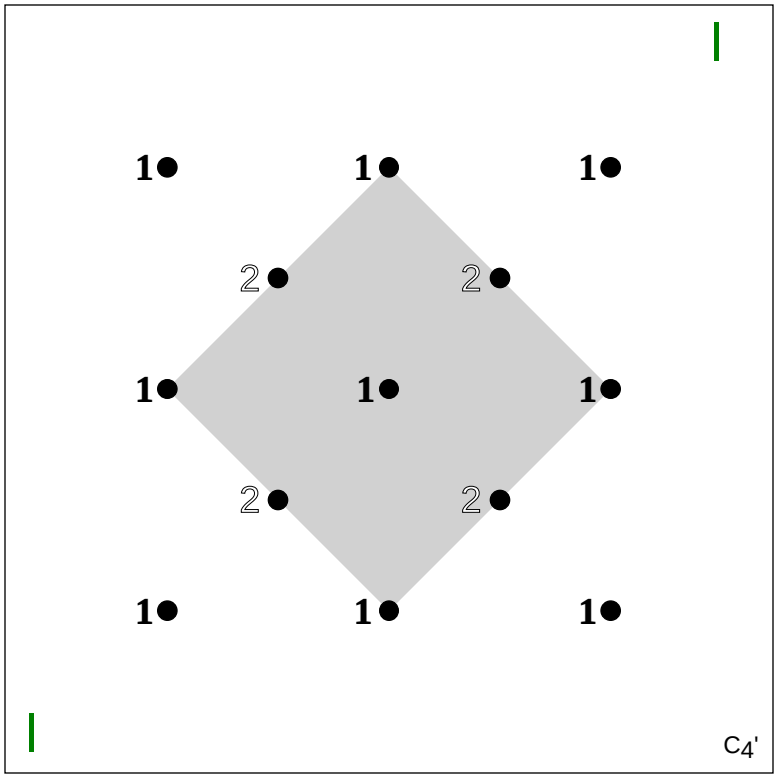
To build more than a unit cell:

- Place rods in additional holes before placing spheres. Follow the same directions as above.
- When building the structure higher, repeat the layers in order.

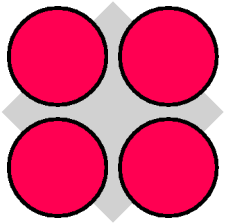
Template *D* (half-size)



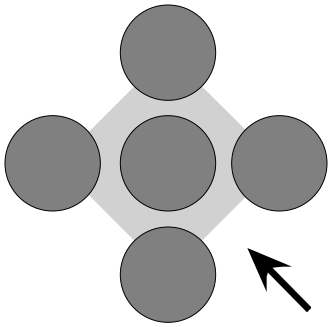
Pattern (actual size)



Unit cell layers (half-size)



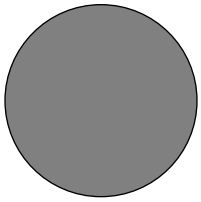
layer 2, *z* = 1/2



layer 1, *z* = 0

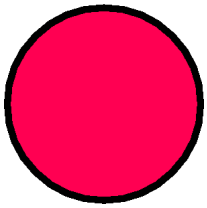
View from side for same orientation as low temperature NiTi.

1, 1' =



colorless

2 =



colored

Coordination Geometries

These models are useful in becoming familiar with tetrahedral, octahedral, cubic, and twelve-coordinate geometries. Alternatively, primitive cubic or close-packed (hcp or ccp) structures can be built and the green, blue, and pink spheres tested for fit in the spaces between the large packing spheres.

This section contains the following:

1) Radius Ratio Coordination Geometries
   Comparison of Coordination number 8, 6, and 4
   Coordination number 8 (body diagonal)
   Comparison of Coordination number 6 and 4 (body diagonal)
   Coordination number 8 (interpenetrating)
   Coordination number 6 (interpenetrating)
   Coordination number 4 (interpenetrating)

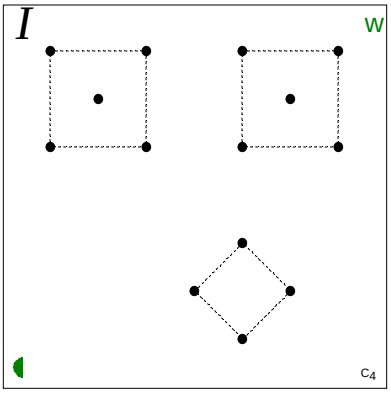
2) Equal Spheres Coordination Geometries
   Coordination number 12
   Coordination number 8
   Coordination number 6
   Coordination number 6 (body diagonal)
   Coordination number 4

Coordination Numbers 8, 6, and 4

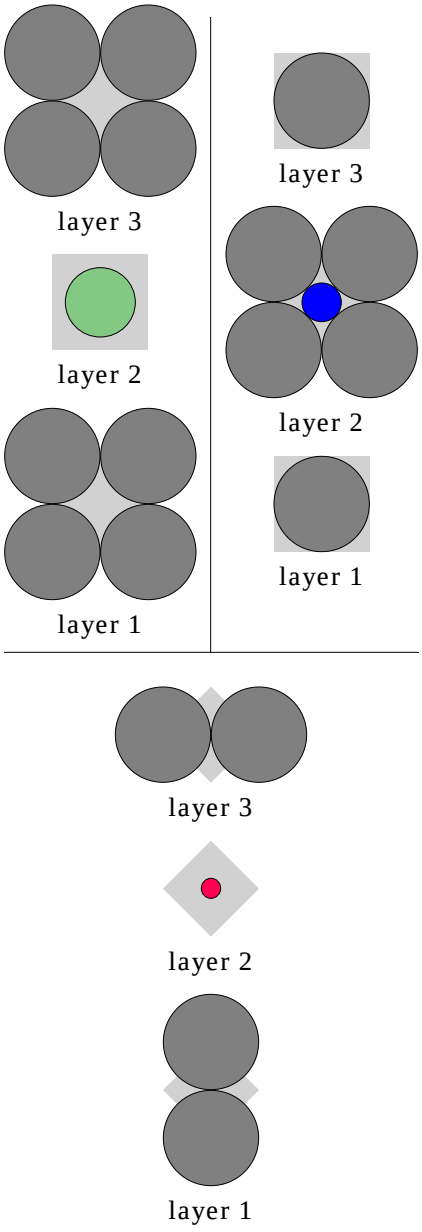
To build the coordination geometry:

- Position the won template *I* in the same corner as the matching won on the base and align holes.
- Insert rods in all 14 holes.
- Build each layer in numerical order, **1** through **3**, as described in the example directions (but skip sphere 2).
- Put a layer 2 sphere on the tip of an extra rod, tilt the model, lift a layer **3** sphere, and use the rod as a pointer to place the layer 2 sphere as shown below. Remove the pointer.

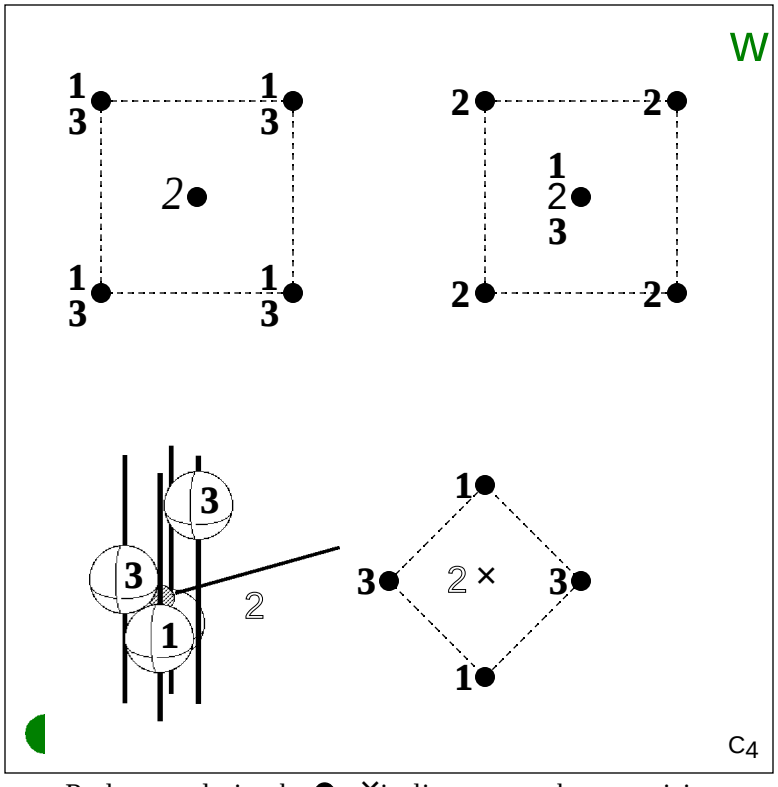
Template *I* (half-size)



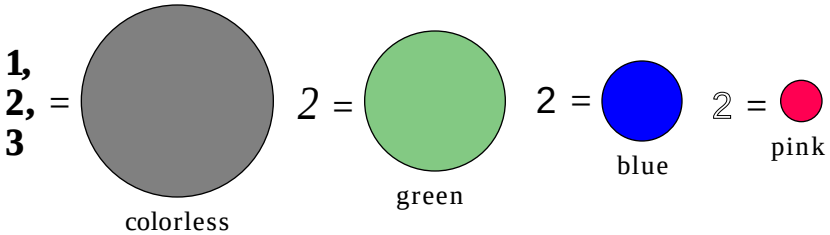
Layer sequence (half-size)



Pattern (actual size)



Rods go only in the ●. ×indicates a sphere position.

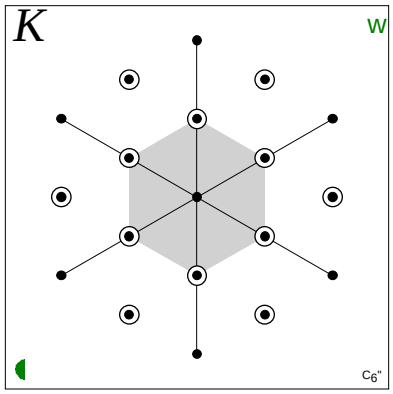


Coordination Number 8 (body diagonal)

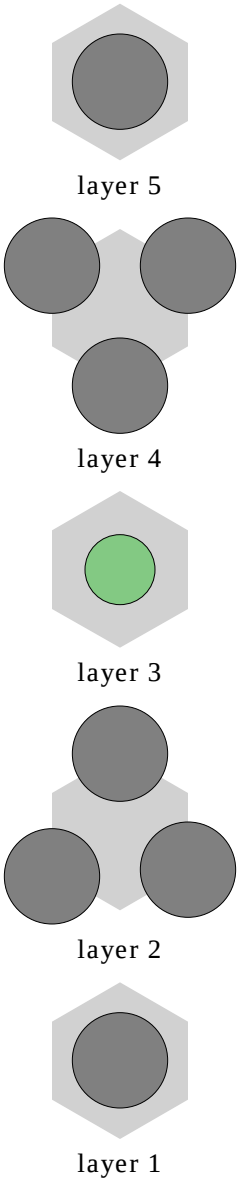
To build the coordination geometry:

- Position the won template K in the same corner as the matching won the base and align holes.
- Insert rods in all 7 holes in the shaded region.
- Build each layer in numerical order, **1** through **5**, as described in the example directions. Finish each layer before starting the next layer.

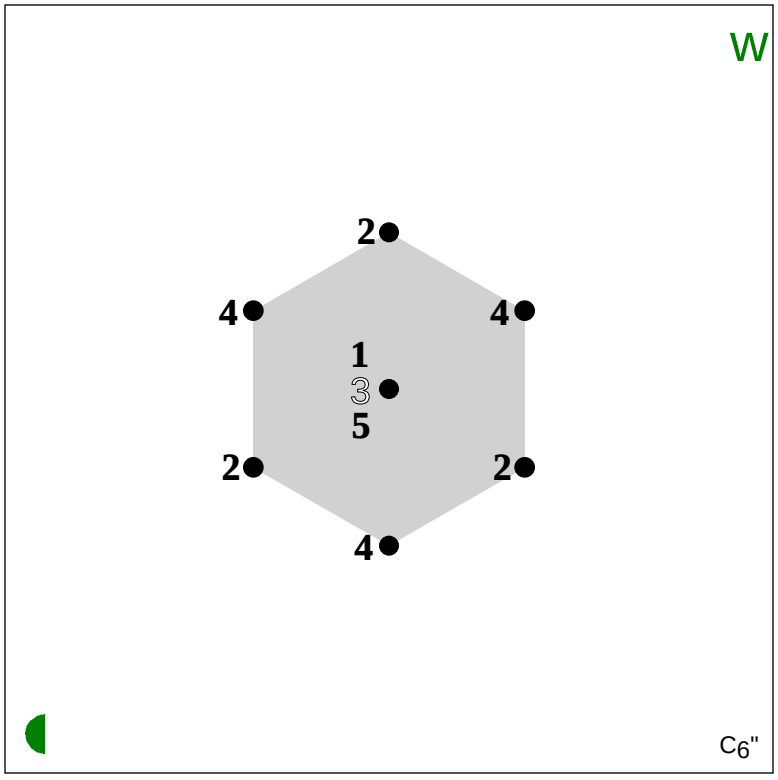
Template K (half-size)



Layer sequence (half-size)



Pattern (actual size)



1, 2, 4, 5 = colorless

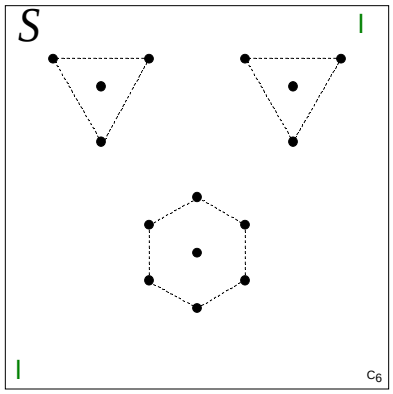
3 = green

Coordination Numbers 6 and 4 (body diagonals)

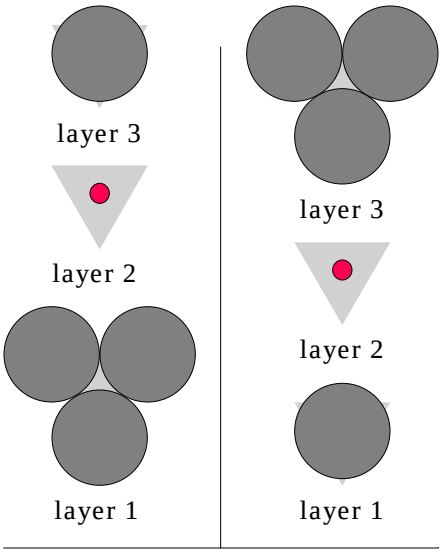
To build the coordination geometry:

- Position the | on template *S* in the same corner as the matching | on the base and align holes.
- Insert rods in all 15 holes.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.

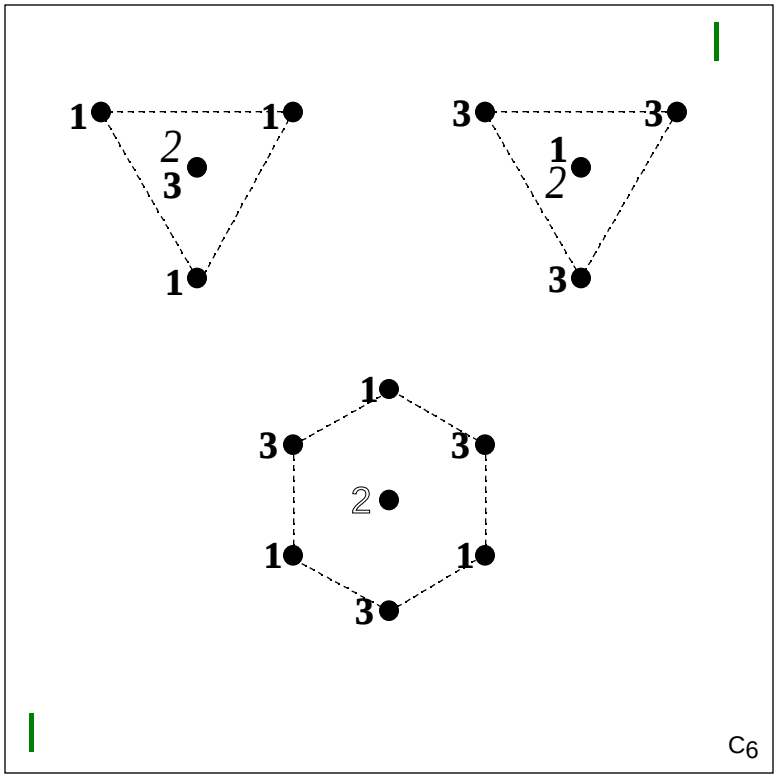
Template *S* (half-size)



Layer sequence (half-size)



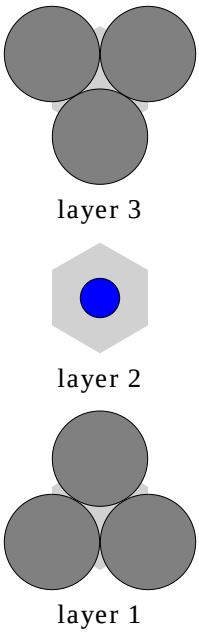
Pattern (actual size)



1, 2, 3 = colorless

2 = blue

2 = pink

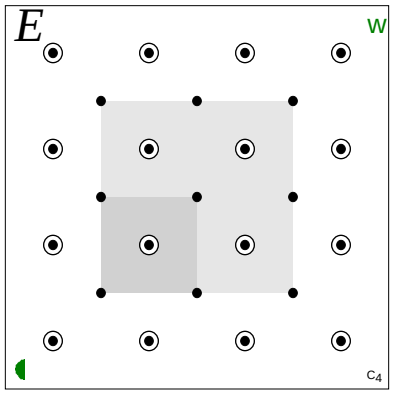


Coordination Number 8 (interpenetrating)

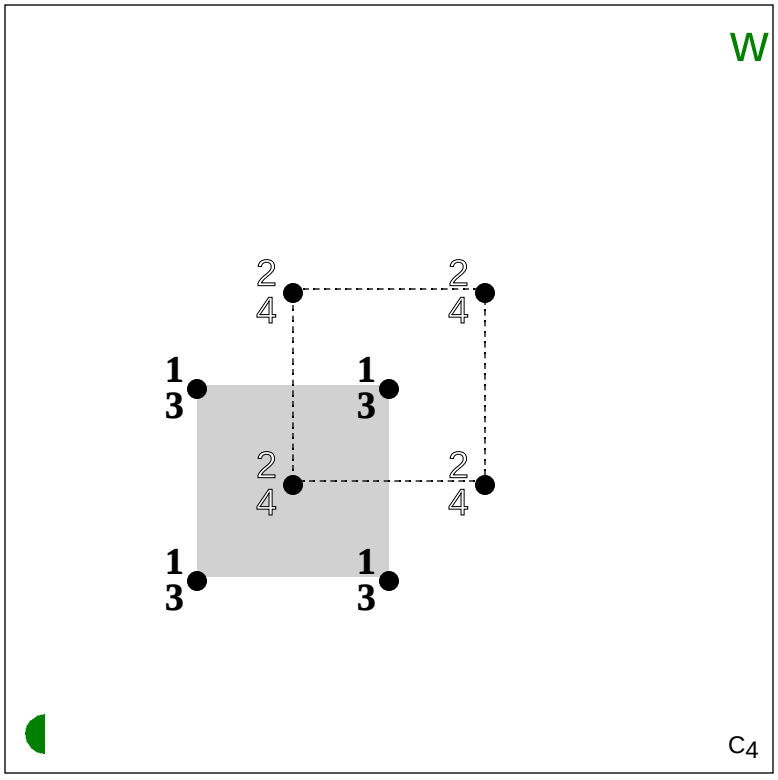
To build the coordination geometry:

- Position the won template E in the same corner as the matching won the base and align holes.
- Insert rods in the 5 holes in the small shaded region and in the remaining 3 circled holes in the large shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.

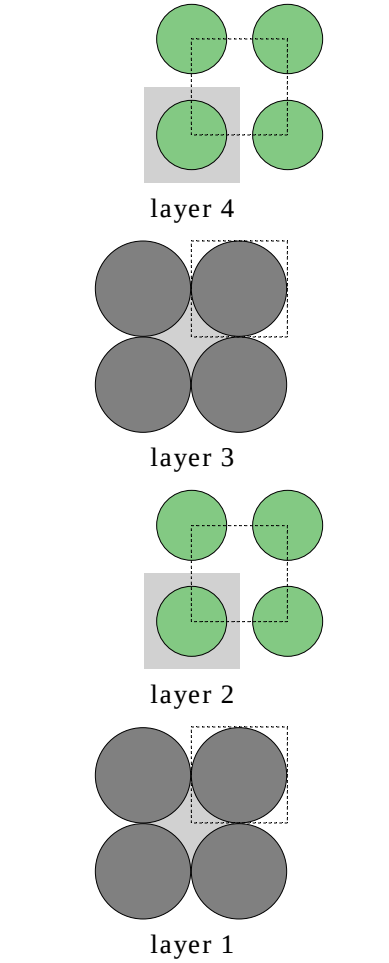
Template E (half-size)



Pattern (actual size)



Layer sequence (half-size)



1, 3 = colorless

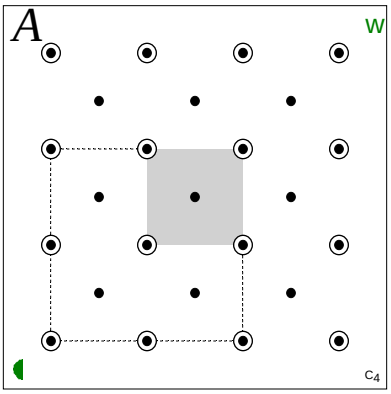
2, 4 = green

Coordination Number 6 (interpenetrating)

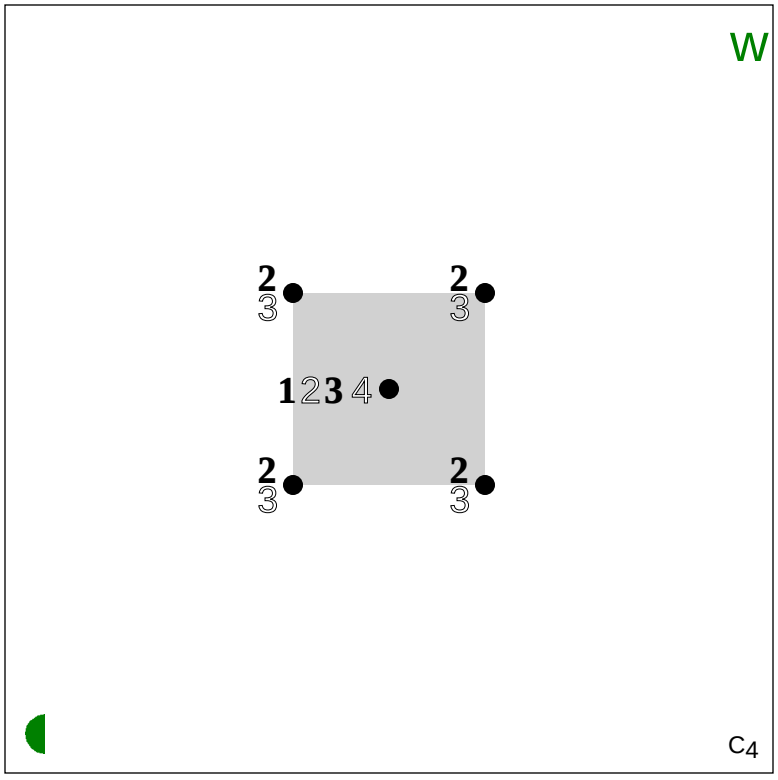
To build the coordination geometry:

- Position the won template *A* in the same corner as the matching won the base and align holes.
- Insert rods in all 5 holes in the shaded region.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.

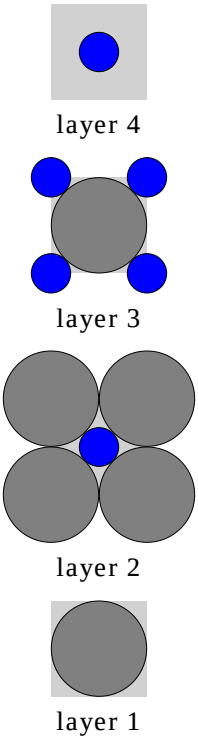
Template *A* (half-size)



Pattern (actual size)



Layer sequence (half-size)



1, 2, 3 = colorless

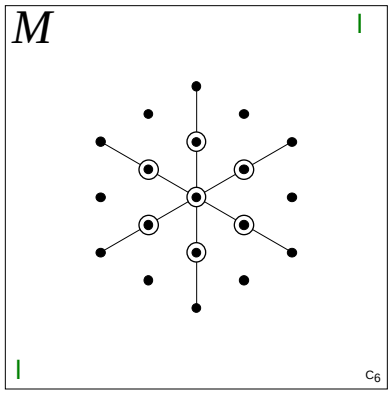
2, 3, 4 = blue

Coordination Number 4 (interpenetrating)

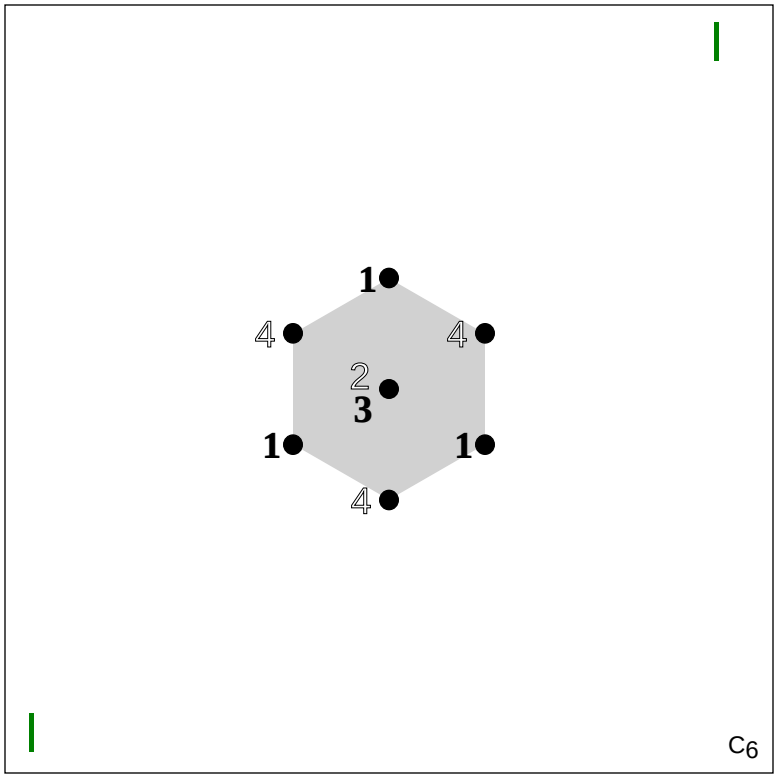
To build the coordination geometry:

- Position the | on template *M* in the same corner as the matching | on the base and align holes.
- Insert rods in the 7 circled holes.
- Build each layer in numerical order, **1** through 4, as described in the example directions. Finish each layer before starting the next layer.

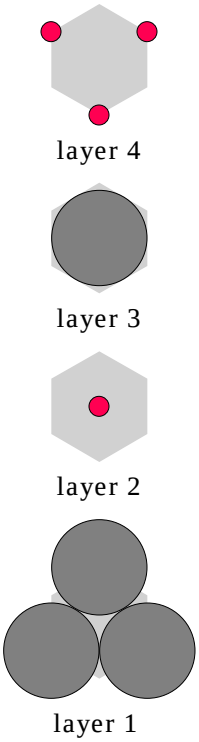
Template *M* (half-size)



Pattern (actual size)



Layer sequence (half-size)



1, 3 = colorless

2, 4 = pink

Coordination Number 12

To build the coordination geometry:

- Position the | on template *L* in the same corner as the matching | on the base and align holes.

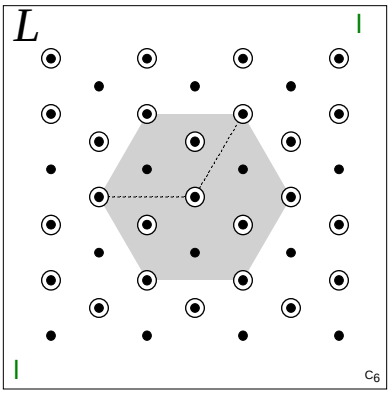
Cubic Close Packed (ccp)

- Insert rods in all 13 holes in the shaded region.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.

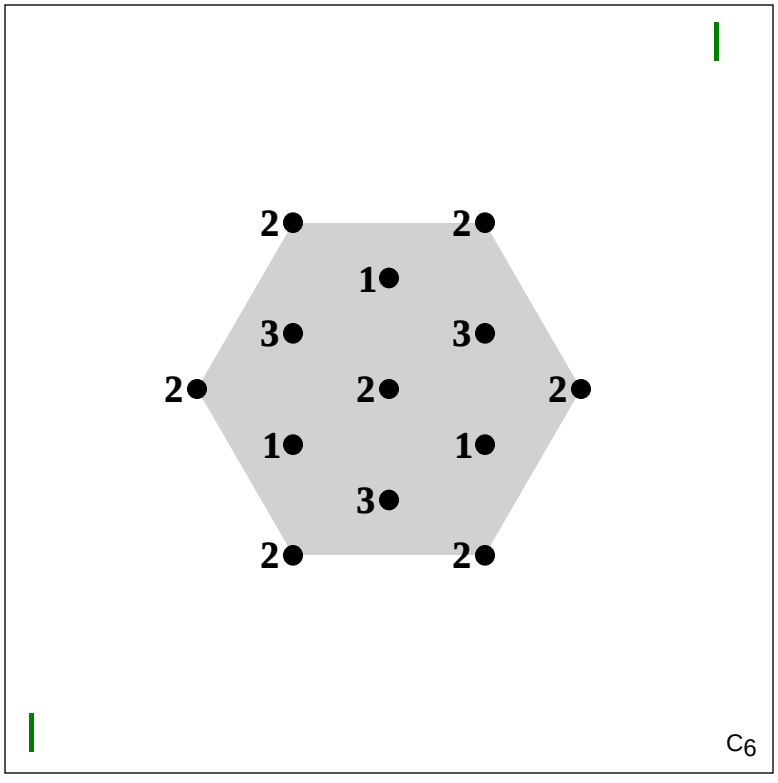
Hexagonal Close Packed (hcp)

- Insert rods in the 10 circled holes in the shaded region.
- Build each layer in numerical order, **1** through **2**, as described in the example directions. Finish each layer before starting the next layer.
- Repeat the first layer (**1'**).

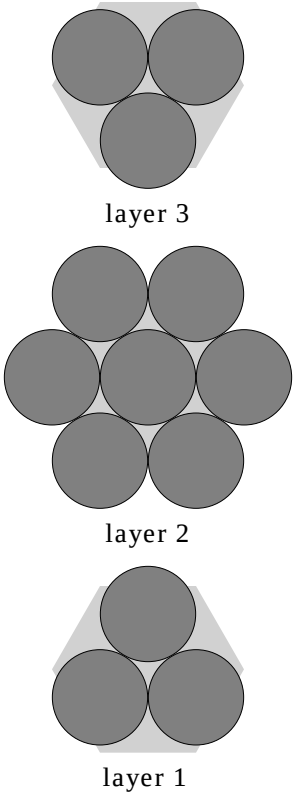
Template *L* (half-size)



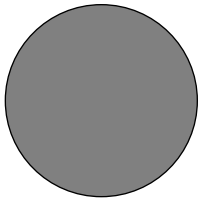
Pattern (actual size)



Layer sequence (half-size)



ccp: 1, 2, 3
hcp: 1, 2, 1'



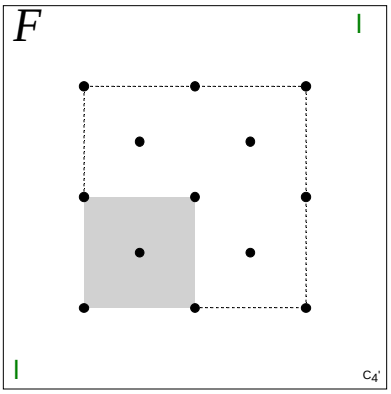
colorless

Coordination Number 8 (equal spheres)

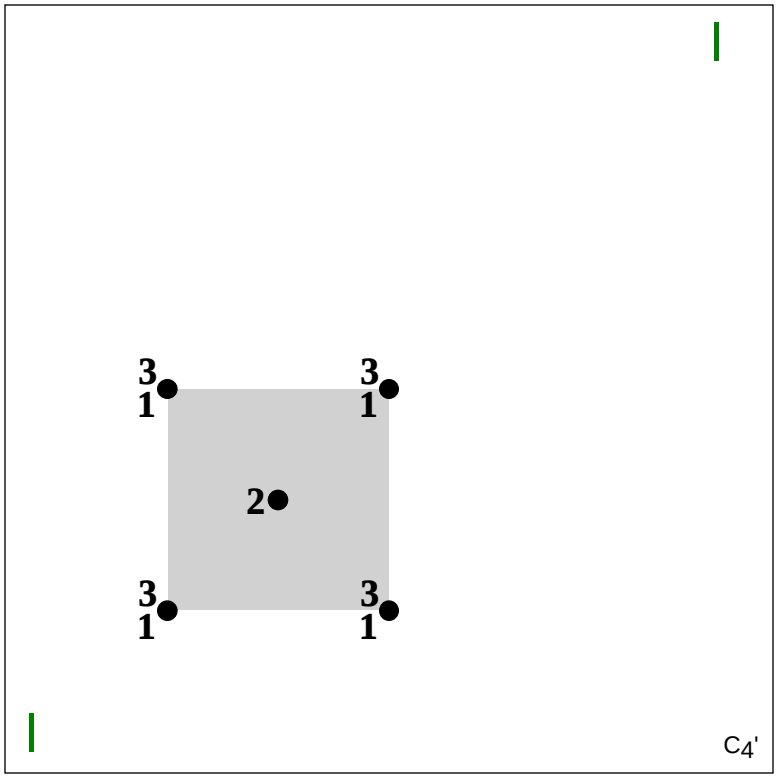
To build the coordination geometry:

- Position the | on template *F* in the same corner as the matching | on the base and align holes.
- Insert rods in all 5 holes in the shaded region.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.

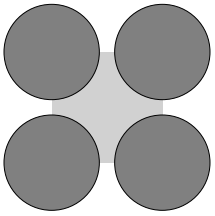
Template *F* (half-size)

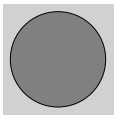


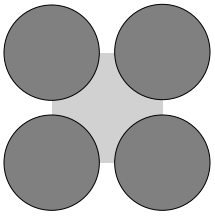
Pattern (actual size)



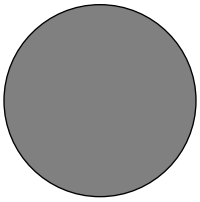
Layer sequence (half-size)


layer 3


layer 2


layer 1

1, 2, 3 =

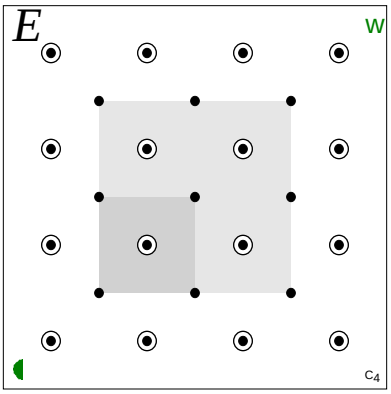

colorless

Coordination Number 6 (equal spheres)

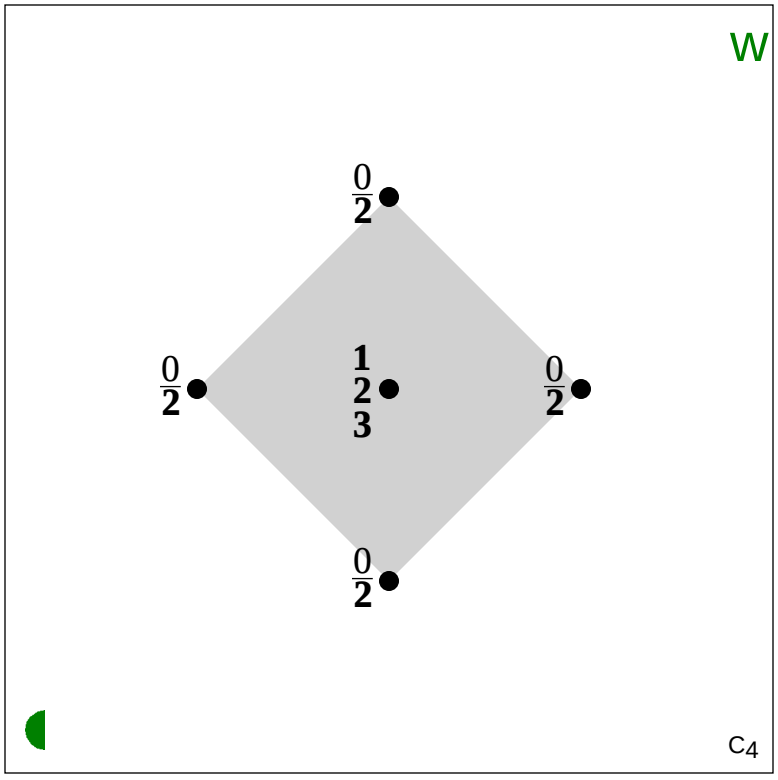
To build the coordination geometry:

- Position the won template E in the same corner as the matching won the base and align holes.
- Insert rods in the uncirlced center hole and in the 4 uncircled edge holes of the entire shaded region.
- Build each layer in numerical order, 0 through **3**, as described in the example directions. Finish each layer before starting the next layer.

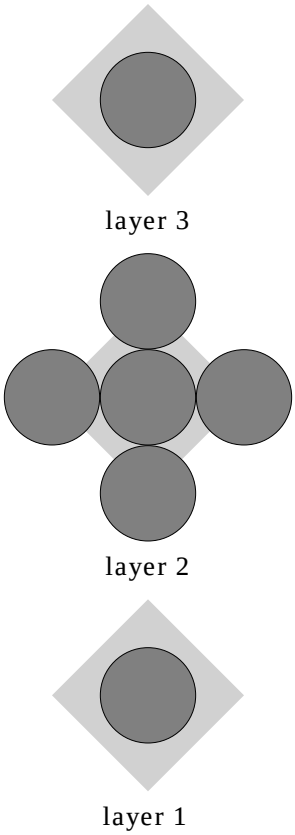
Template E (half-size)

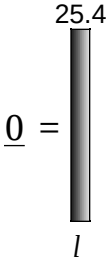


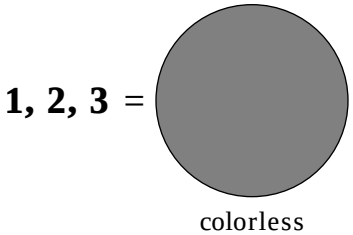
Pattern (actual size)



Layer sequence (half-size)





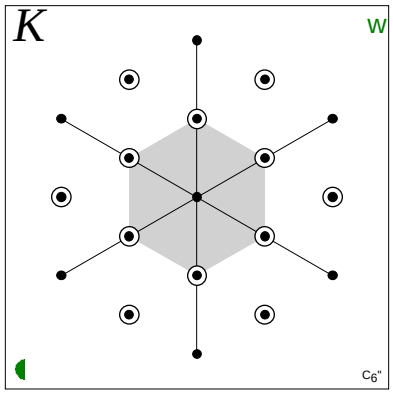


Coordination Number 6 (equal spheres, body diagonal)

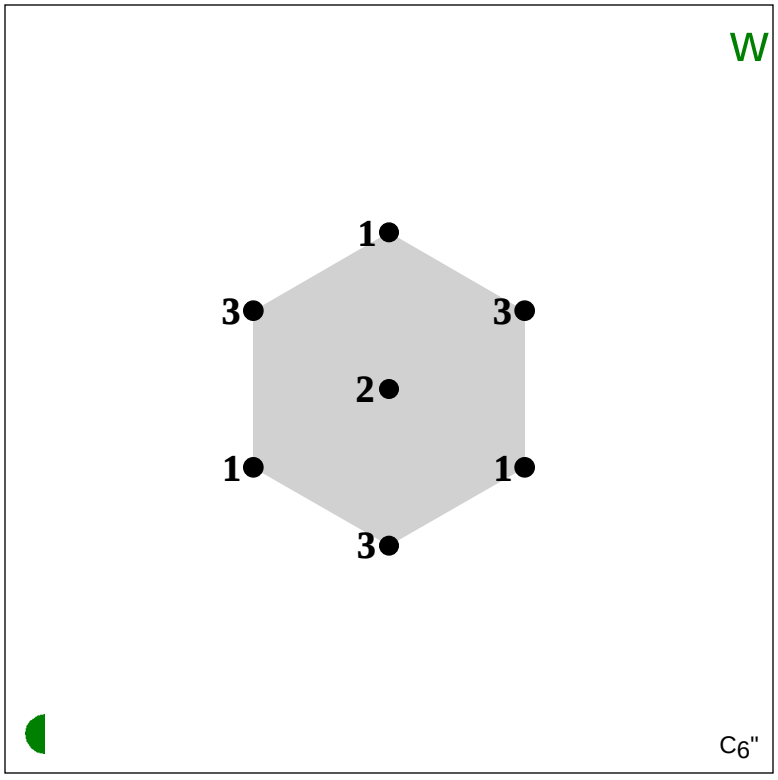
To build the coordination geometry:

- Position the won template *K* in the same corner as the matching won the base and align holes.
- Insert rods in all 7 holes in the shaded region.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.

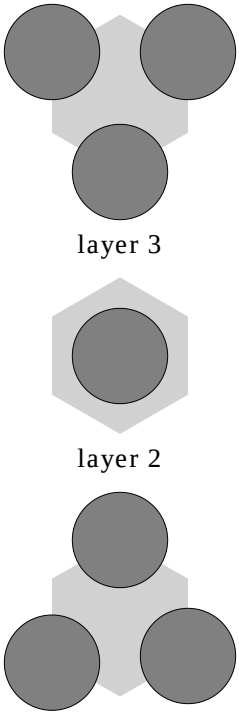
Template *K* (half-size)



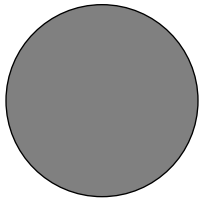
Pattern (actual size)



Layer sequence (half-size)



1, 2, 3 =



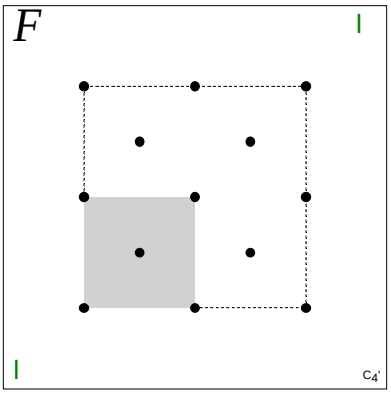
colorless

Coordination Number 4 (equal spheres)

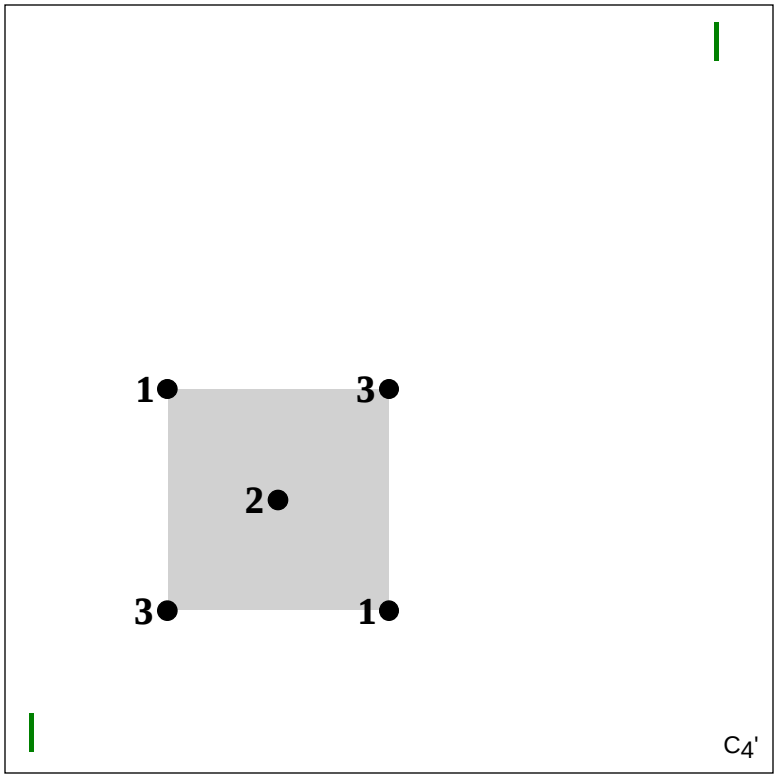
To build the coordination geometry:

- Position the | on template *F* in the same corner as the matching | on the base and align holes.
- Insert rods in all 5 holes in the shaded region.
- Build each layer in numerical order, **1** through **3**, as described in the example directions. Finish each layer before starting the next layer.

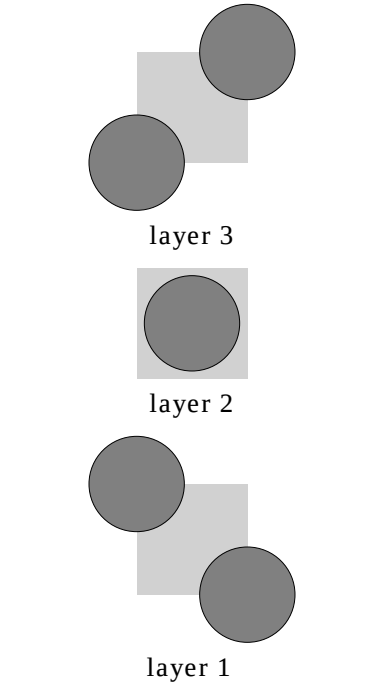
Template *F* (half-size)



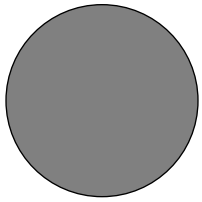
Pattern (actual size)



Layer sequence (half-size)



1, 2, 3 =

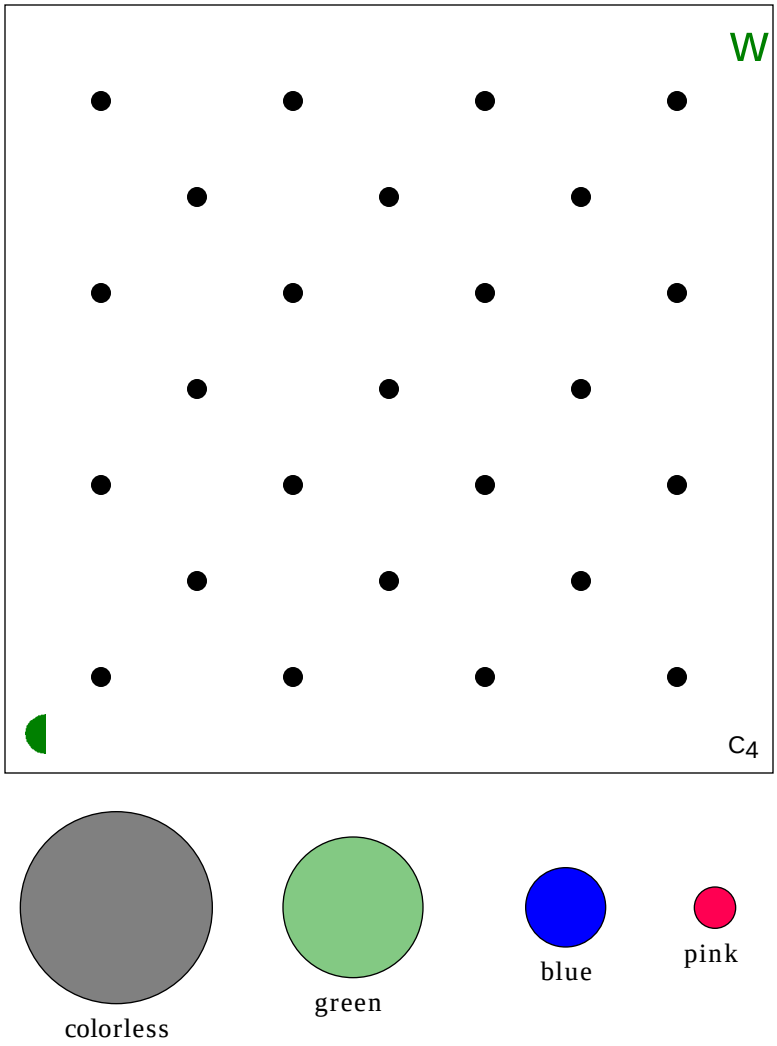


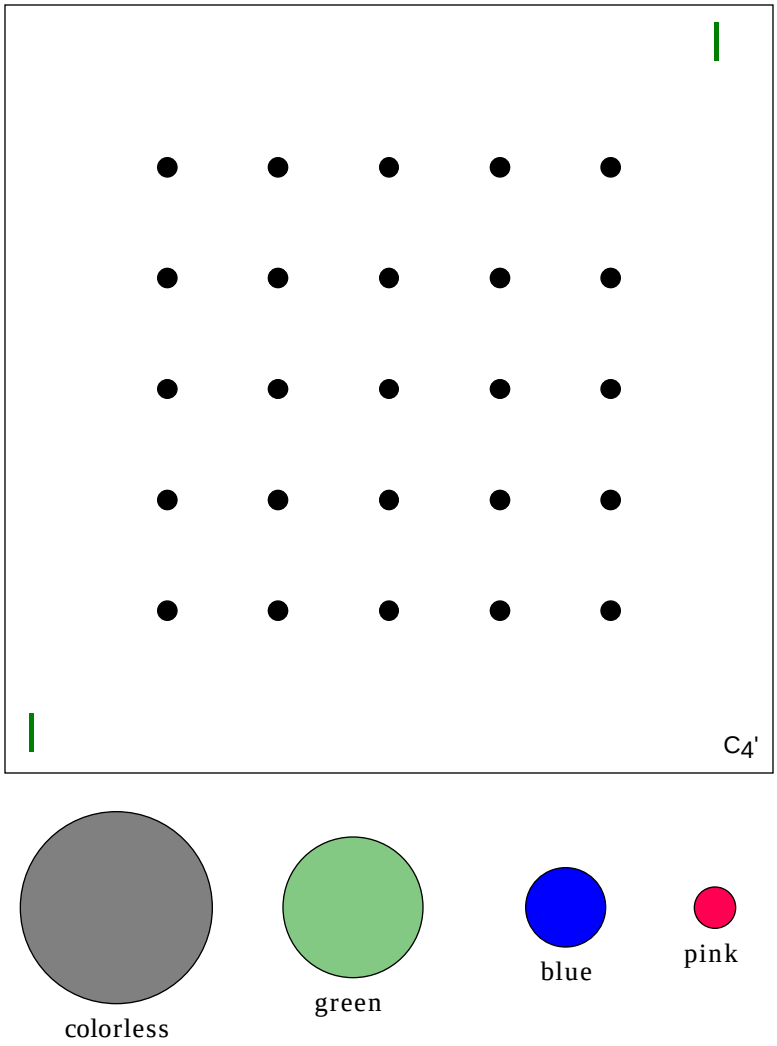
colorless

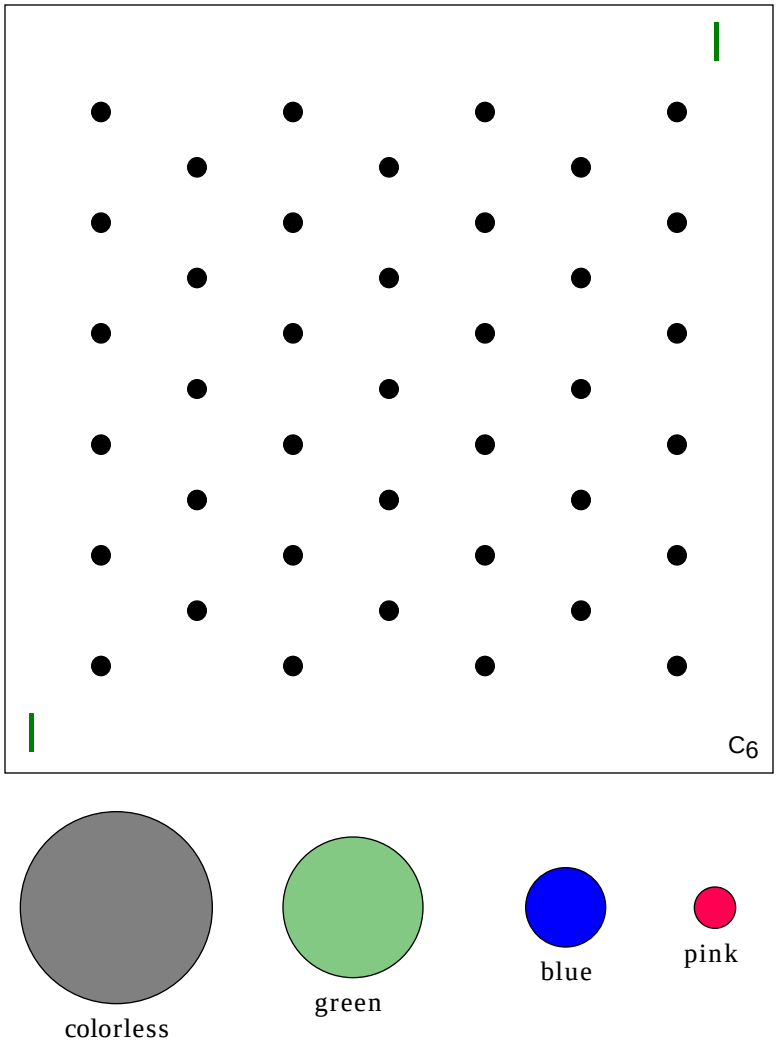
Appendices

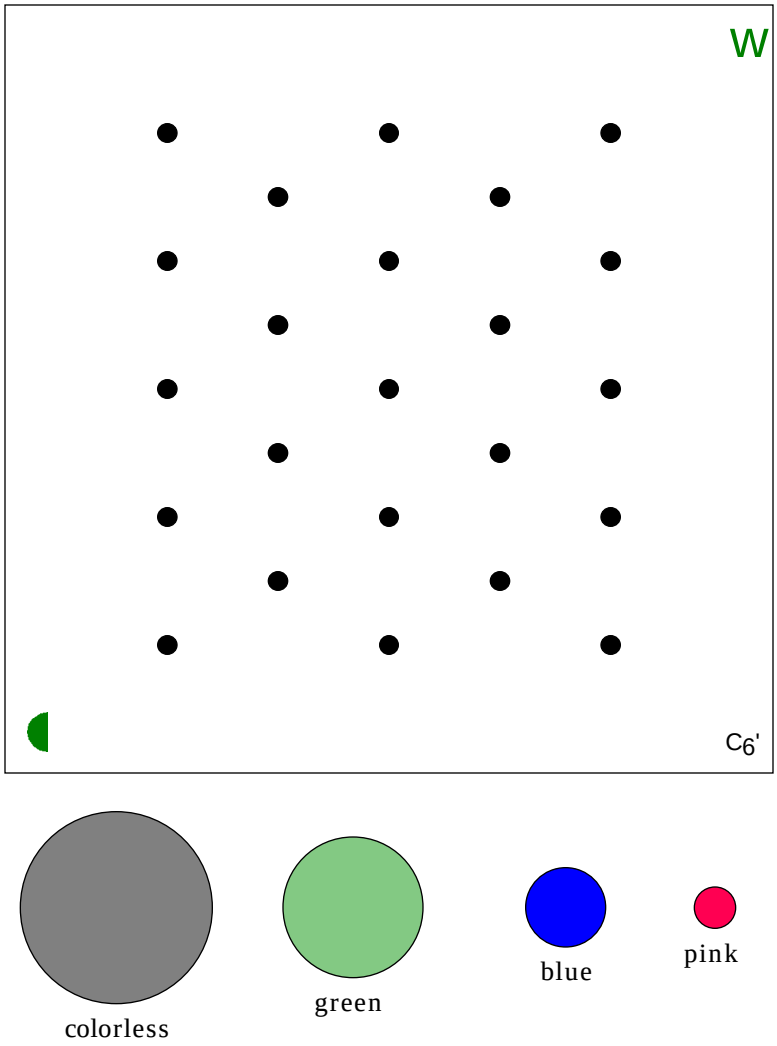
The Appendices contain:

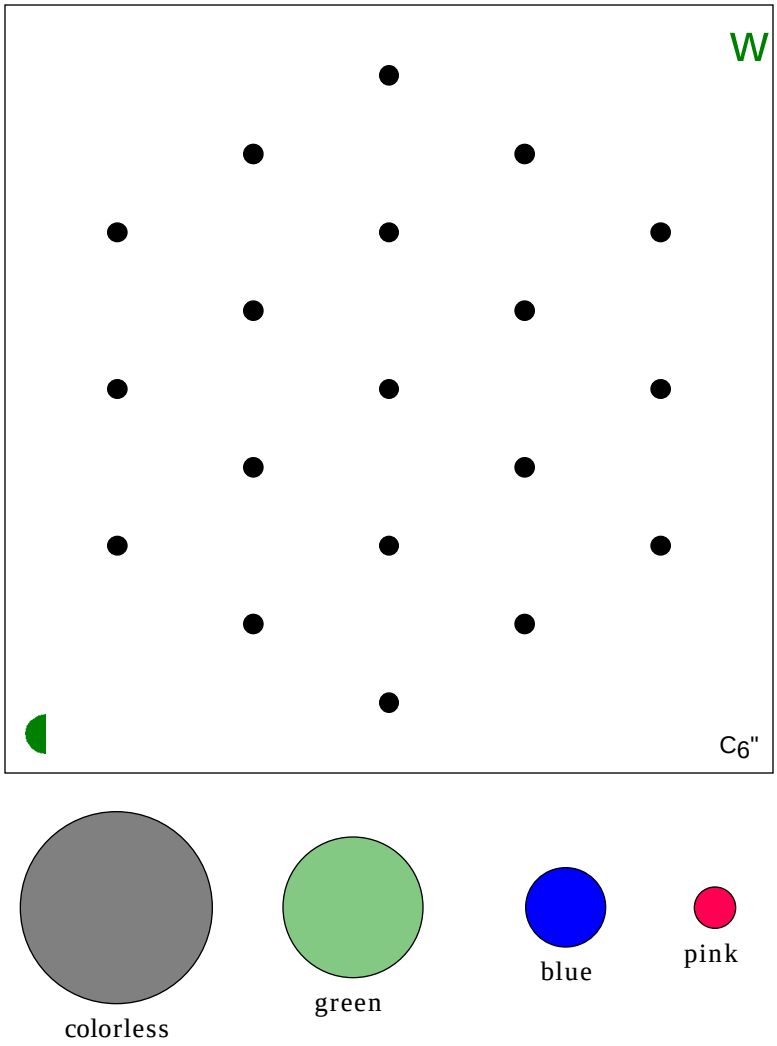
- Blank instruction sheets for creation of new structures.
- A complete set of full-sized template illustrations.
- Half-size template illustrations arranged by increasing unit-cell size for cubic and hexagonal symmetry. If you want to build a structure that is not in this manual, first decide whether you will build it on a square or hexagonal base. Then use these illustrations as a guide to select a template of appropriate unit-cell size; try ones with smaller or larger unit cells as necessary to make the structure stack to the appropriate relative height.
- Full-sized representations of the bases.
- Full-sized representations of all the spacers used in the manual.

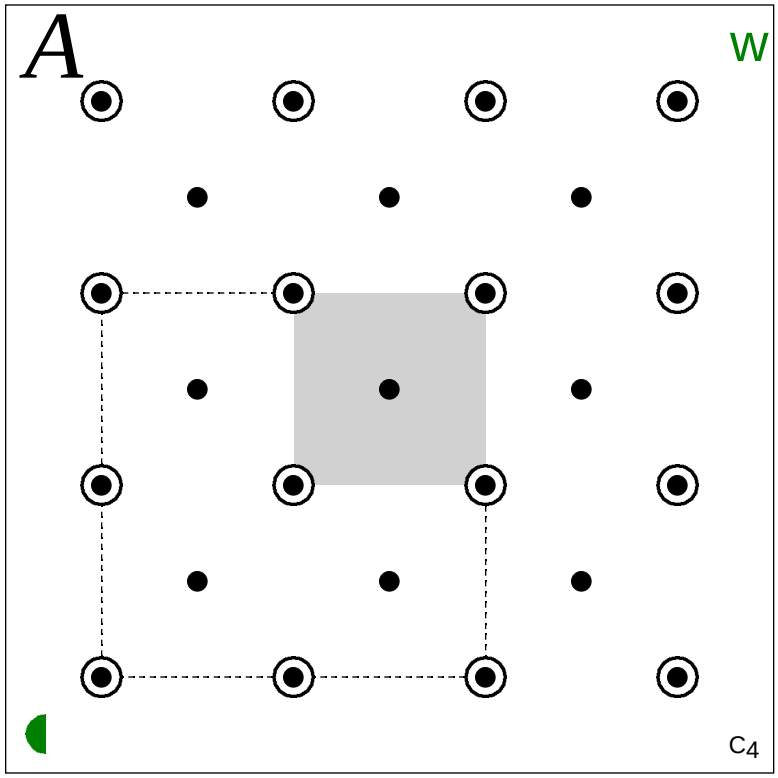

W
C4
colorless
green
blue
pink

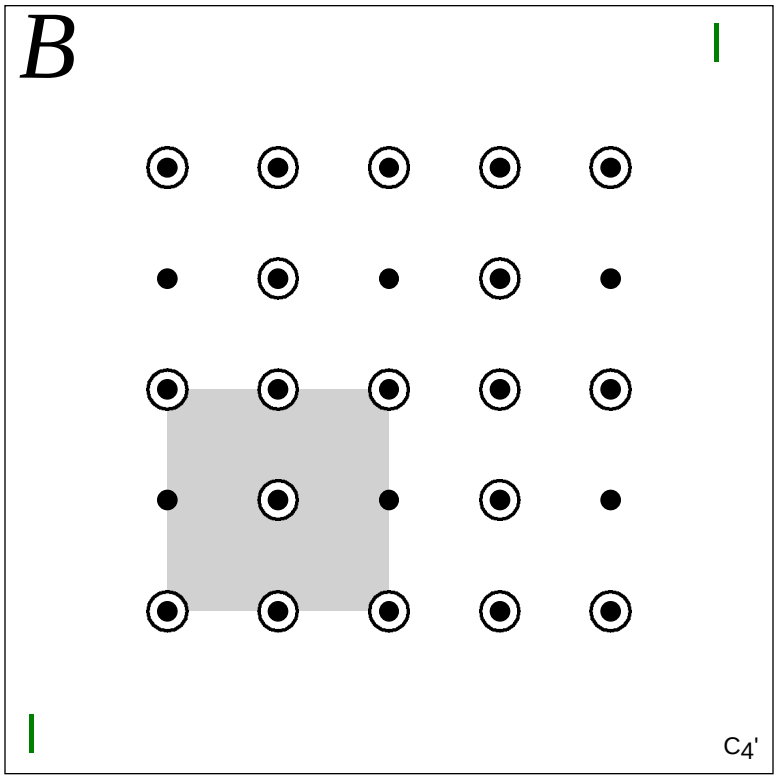

C4'
colorless
green
blue
pink


C6
colorless
green
blue
pink


W
C6'
colorless
green
blue
pink


W
C6"
colorless
green
blue
pink


A
W
C4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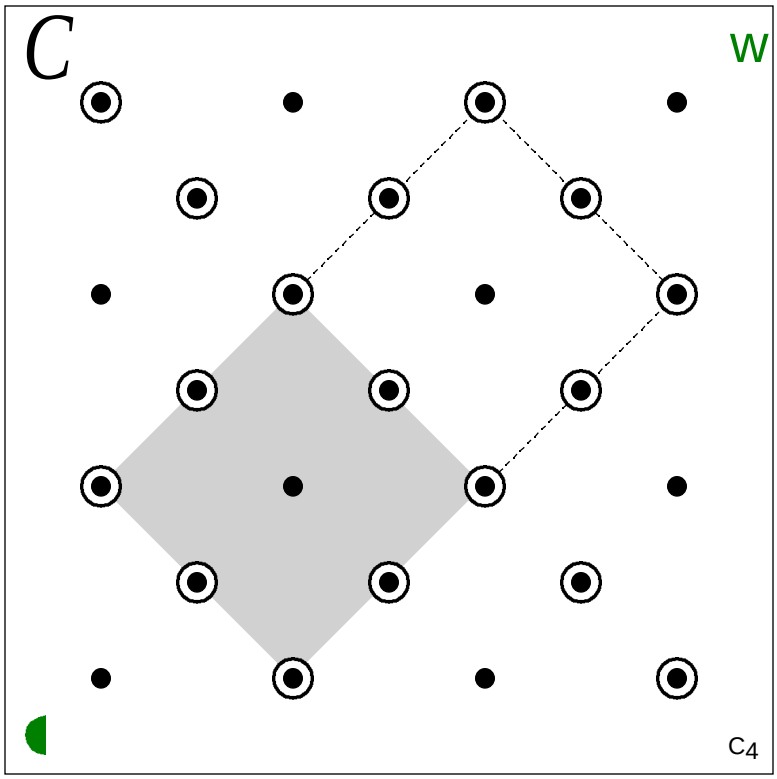
C4'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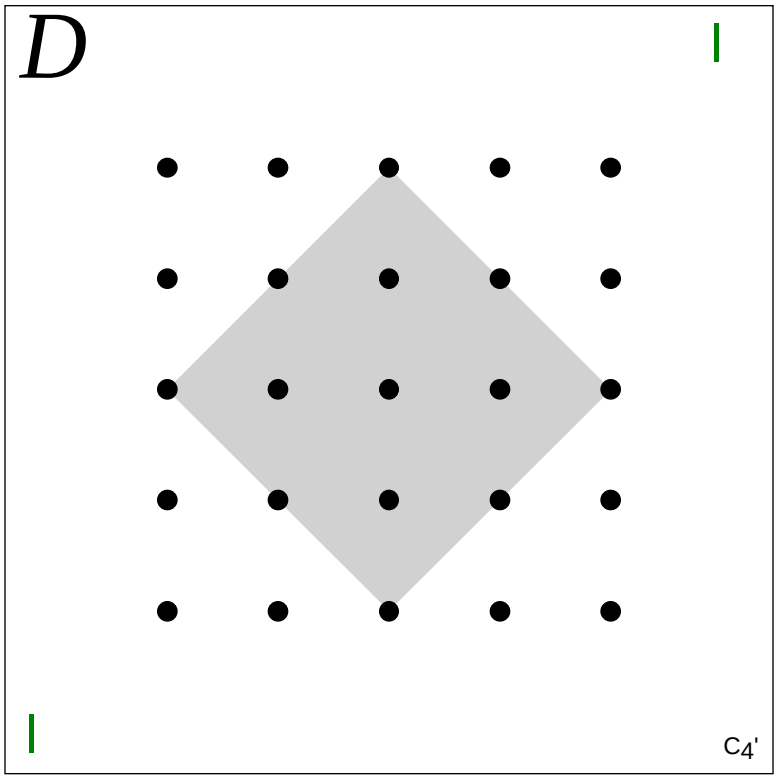
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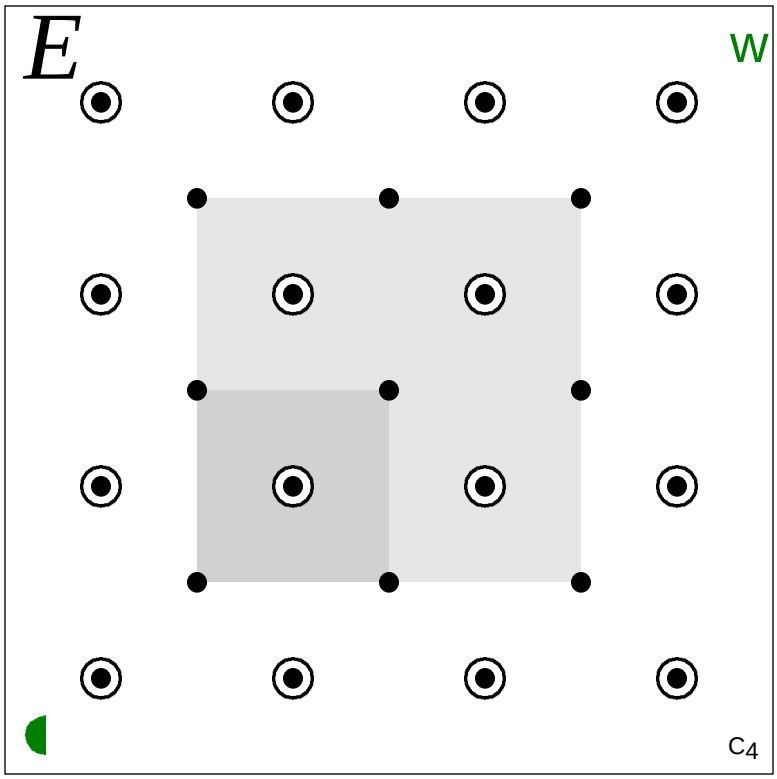
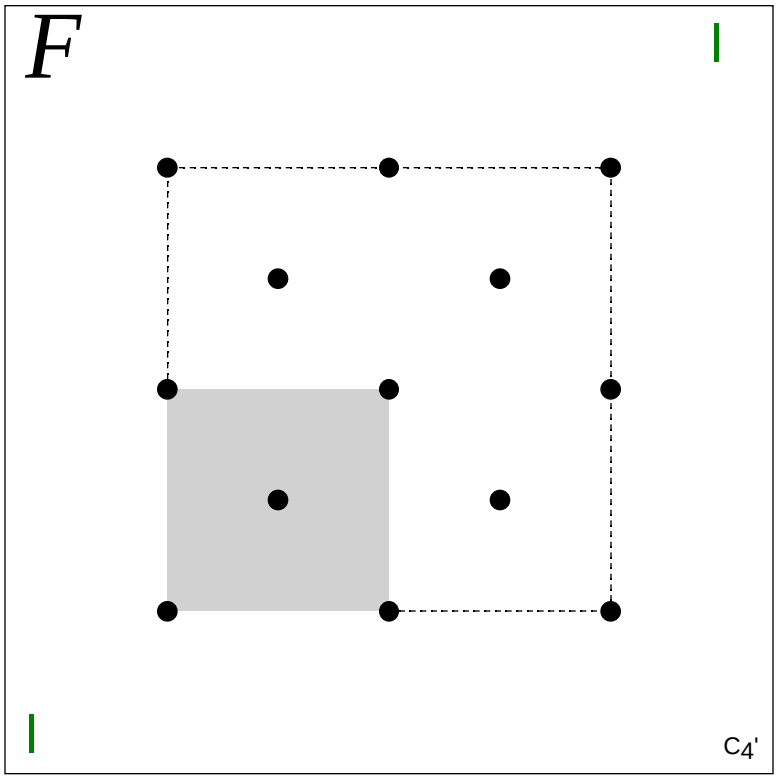
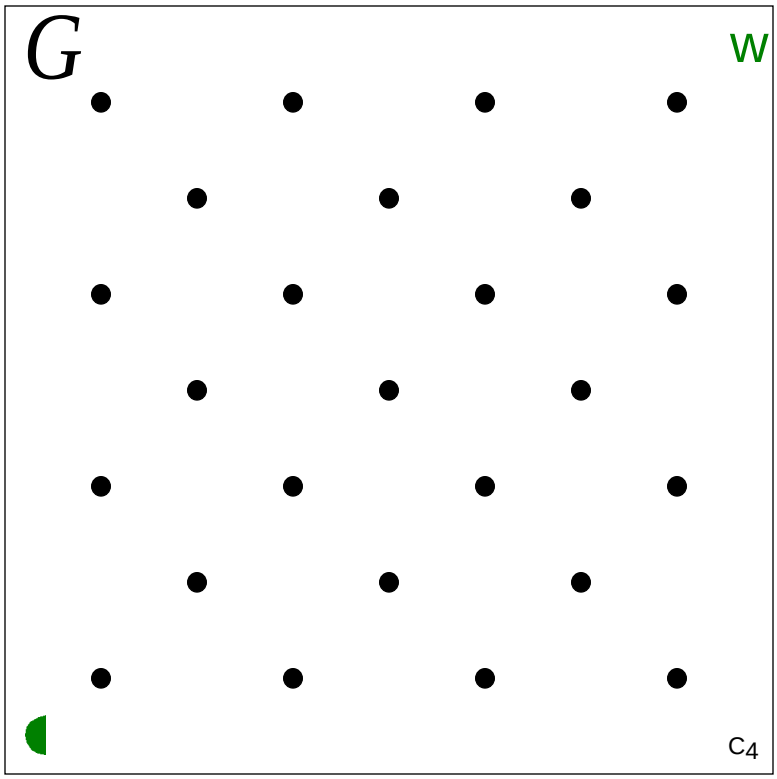
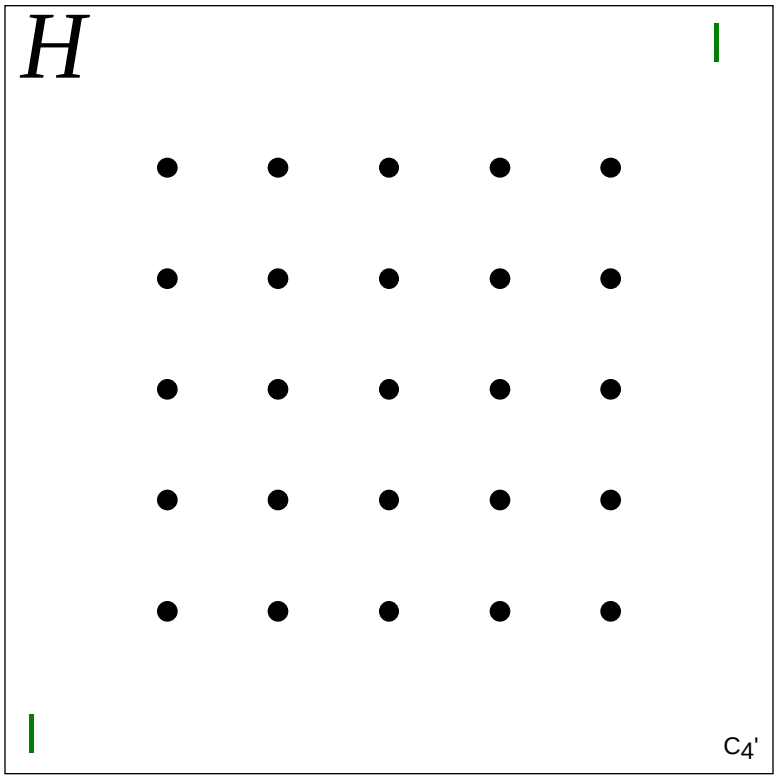
C4'


E
W
C4


F
I
I
C4'


G
W
C4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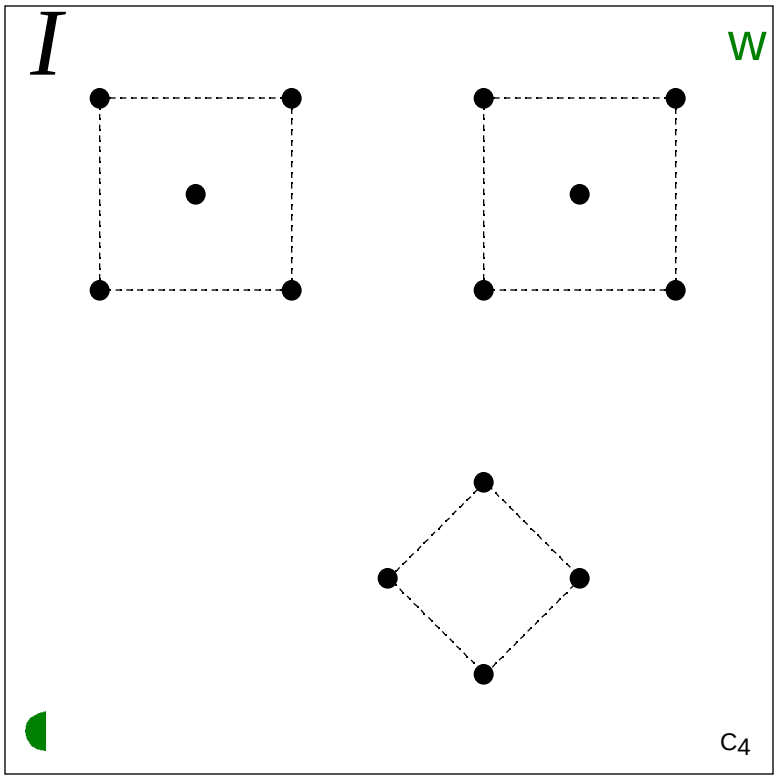
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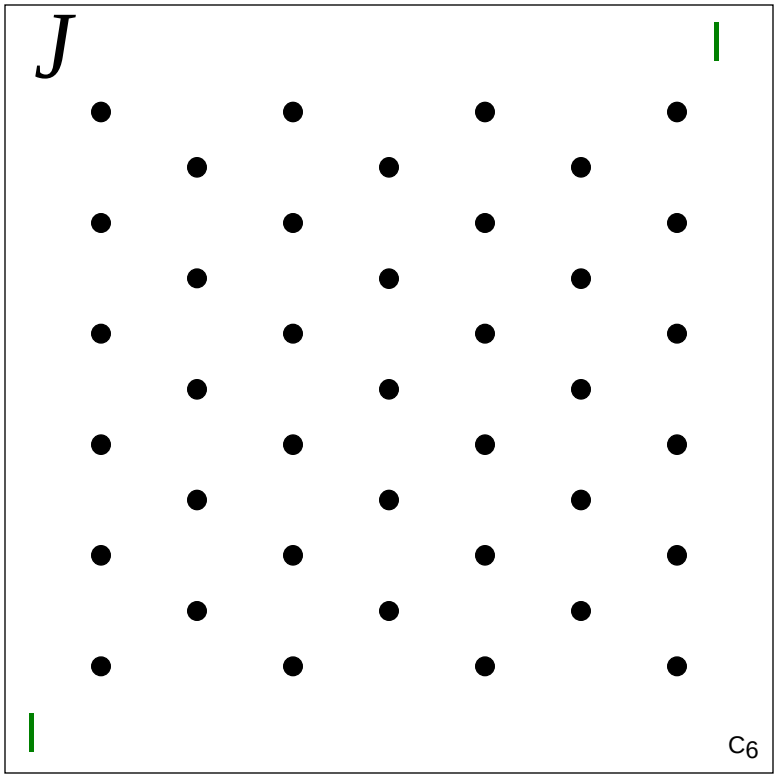
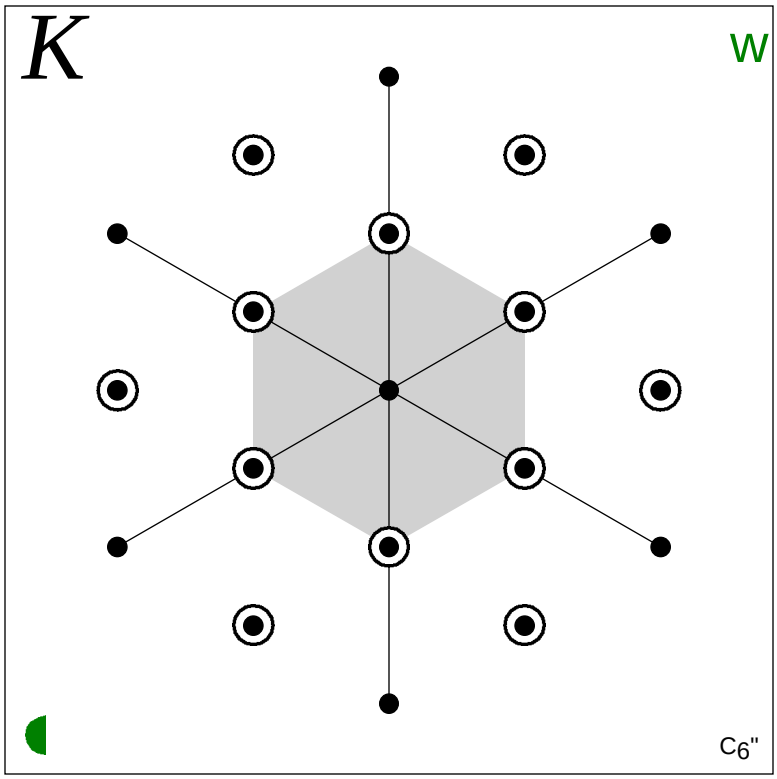

J
C6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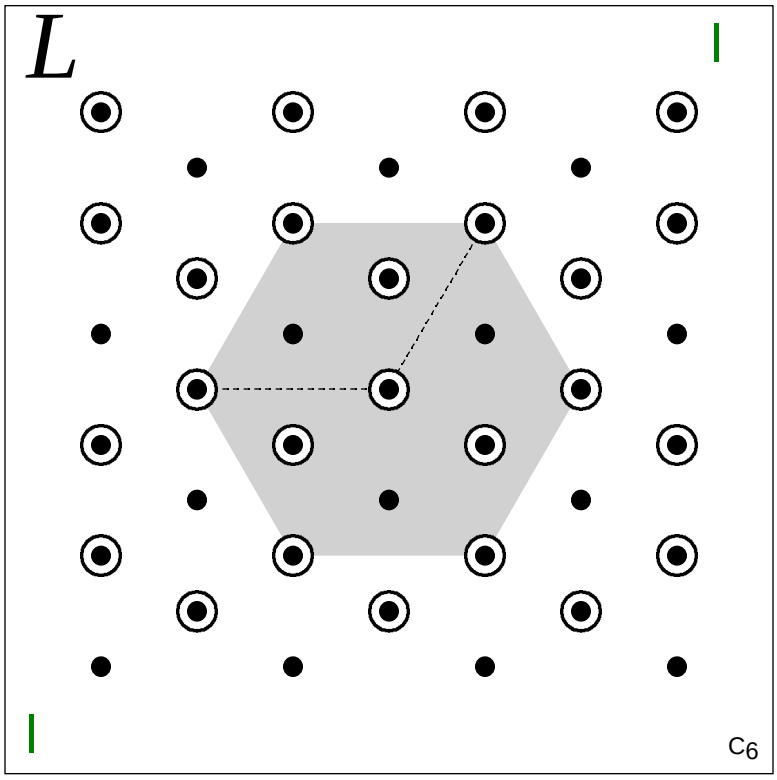
C6"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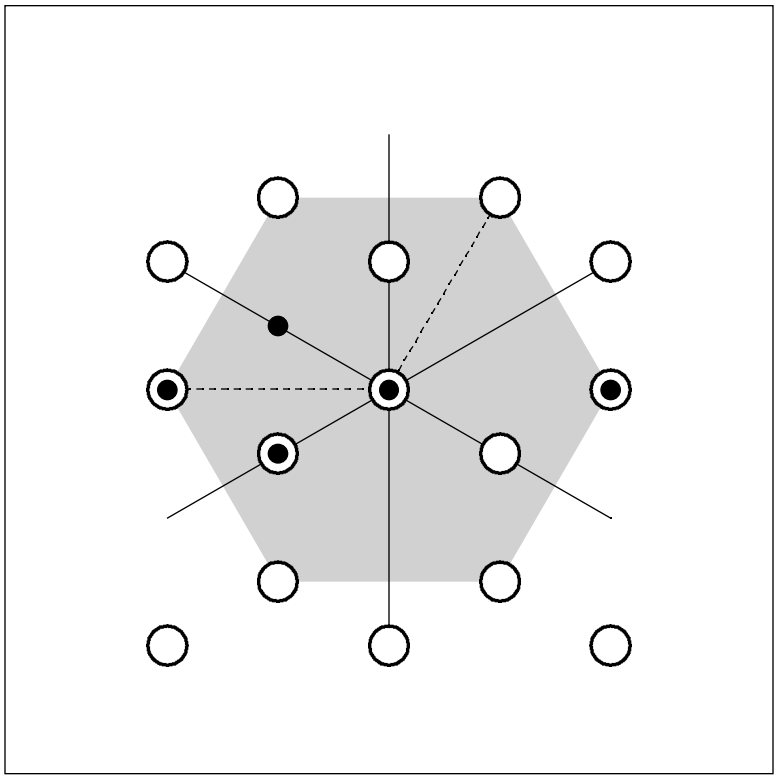
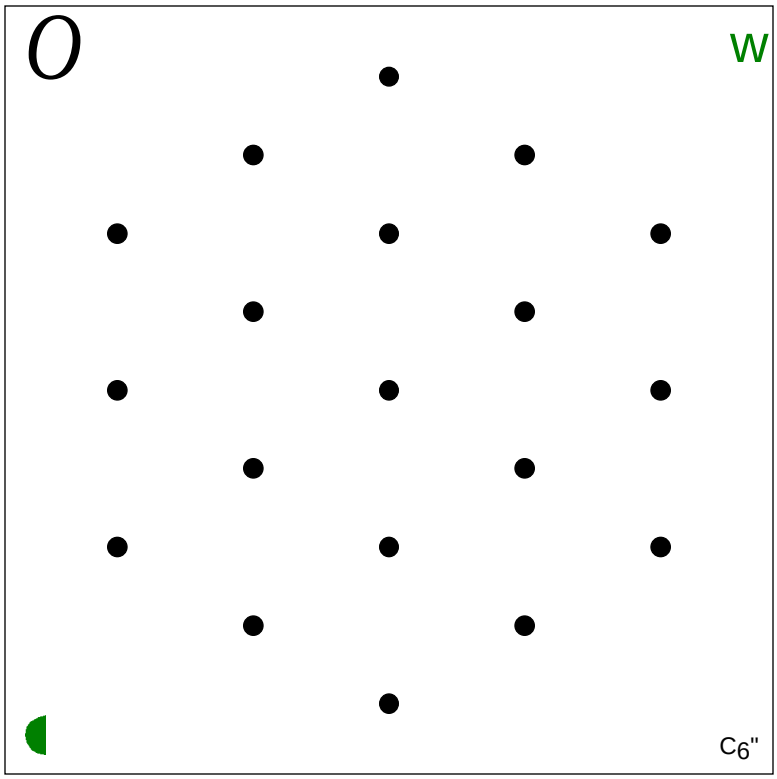
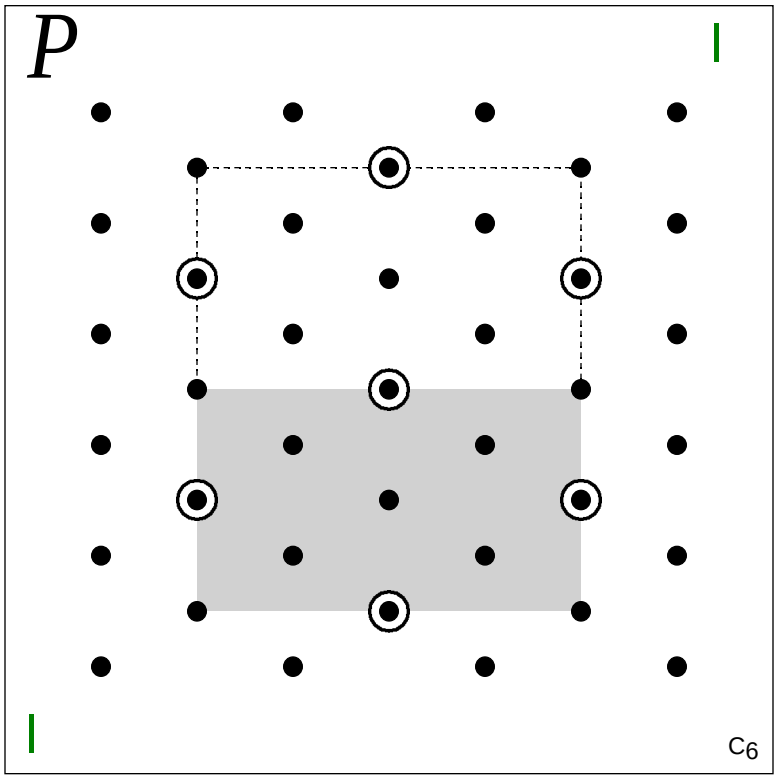
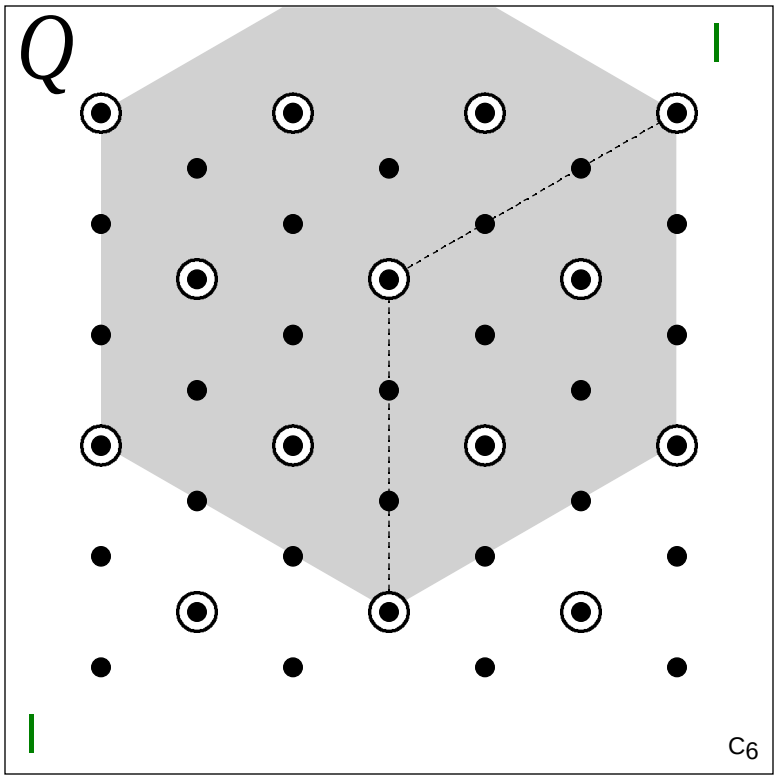
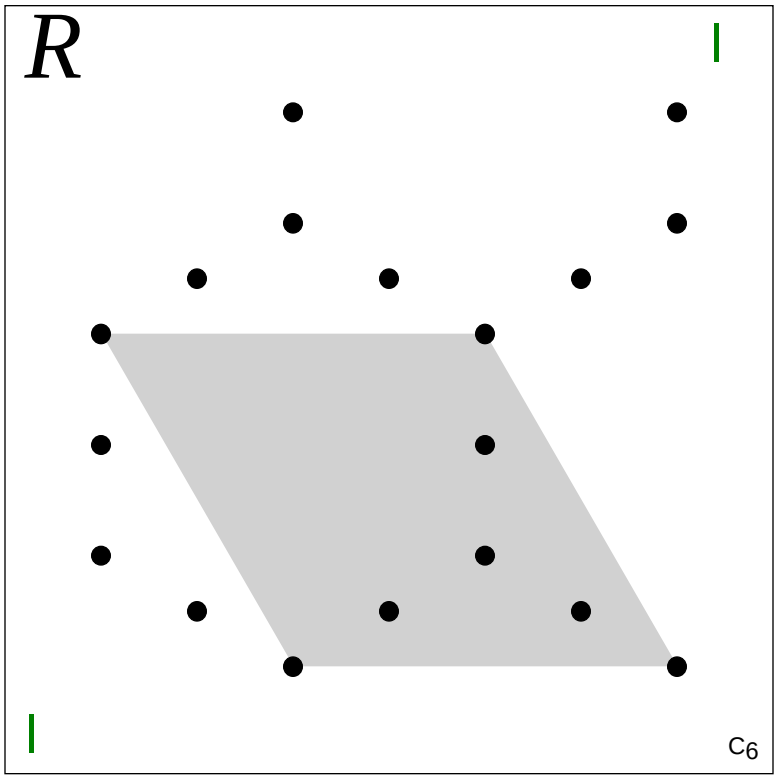
C6

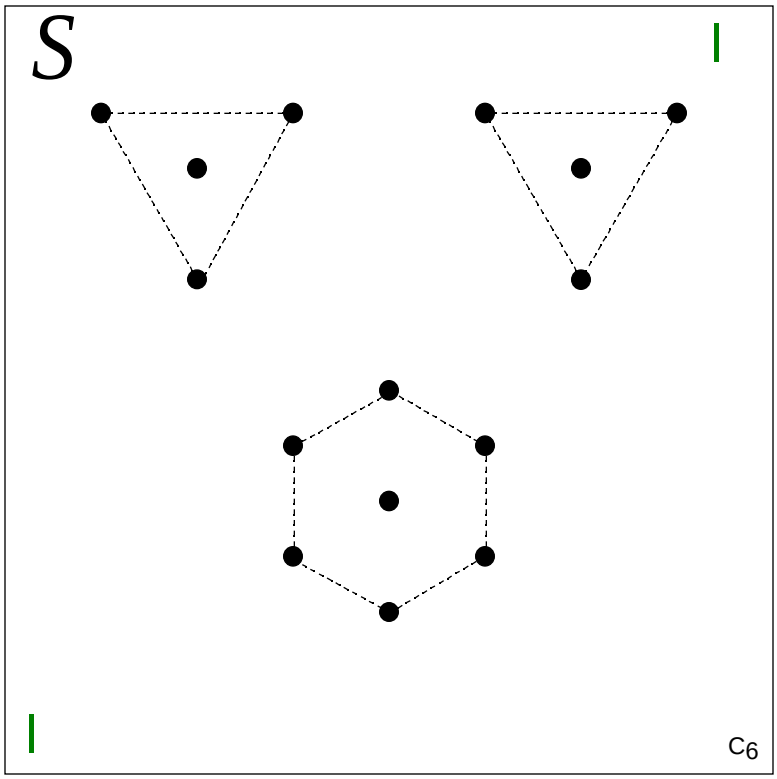


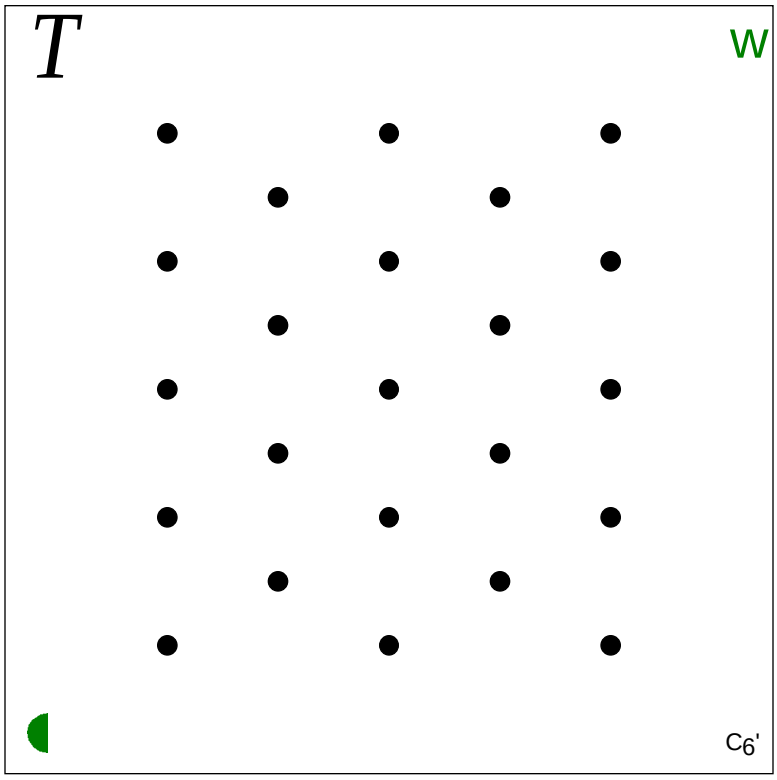

O
W
C6"


P
I
I
C6

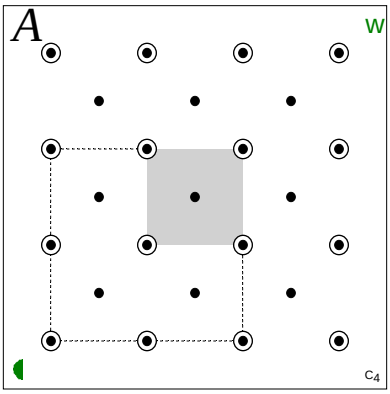

Q
C6

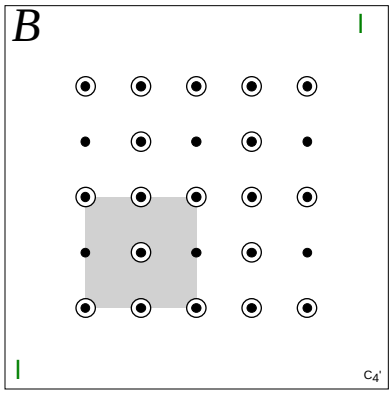

R
C6

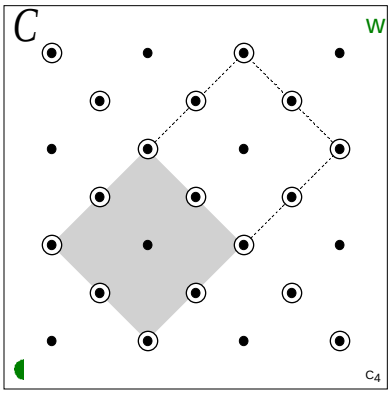

S
I
I
C6

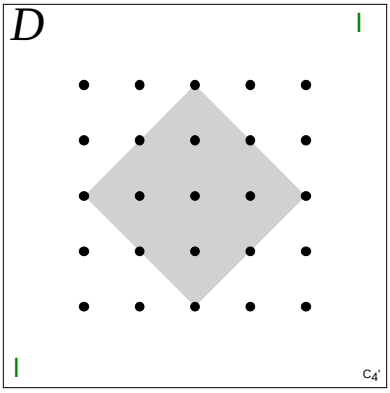

T
W
C6'

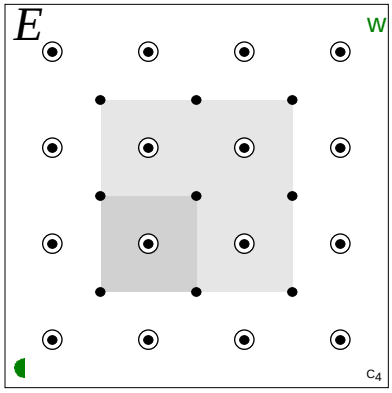
Square Unit Cells of Increasing Size

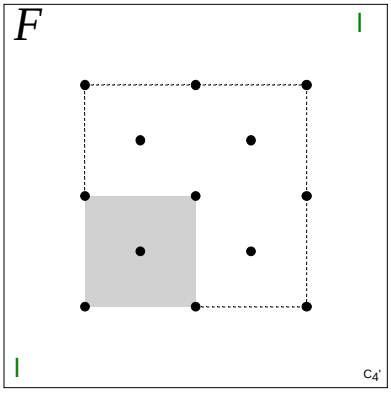


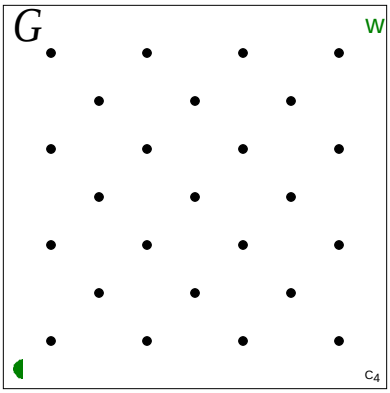




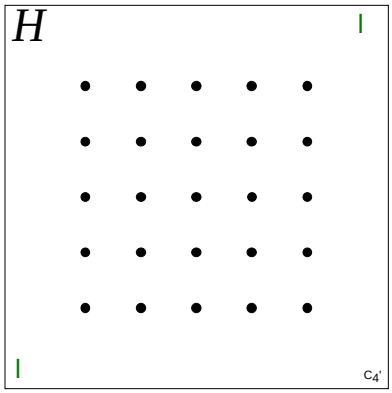




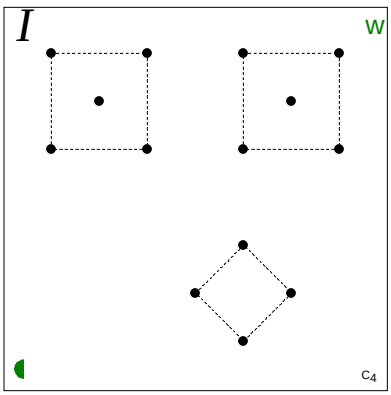




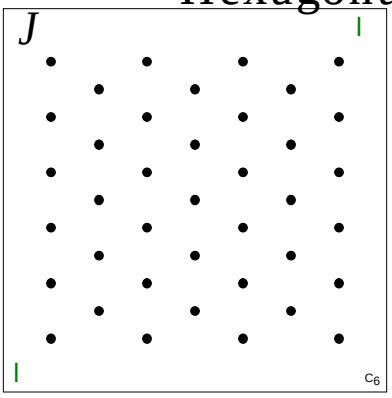
G not included. Use back side of *A*, *C*, or *E*.

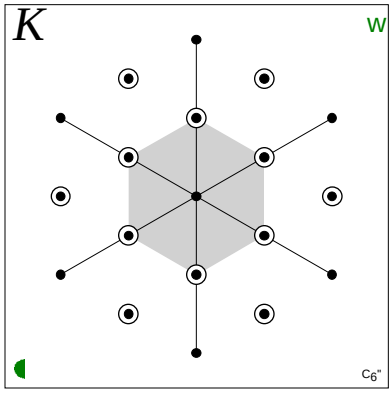


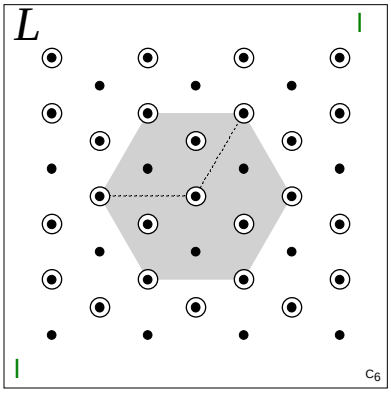
H not included. Use back side of *B* or *D*.



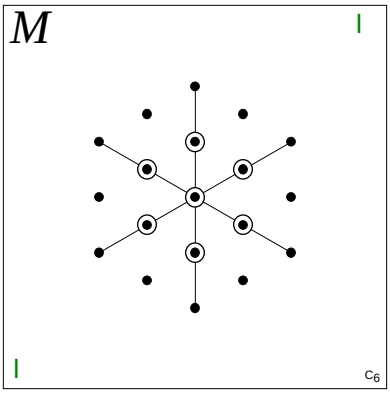
Hexagonal Unit Cells of Increasing Size

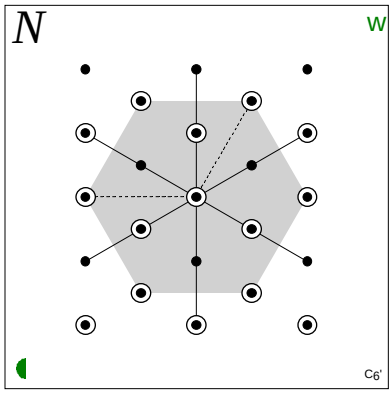


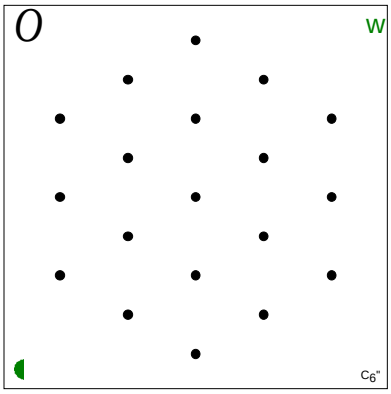




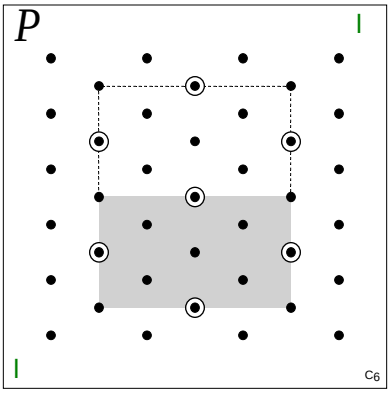
J not included. Use back side of *L*, *P*, or *Q*.

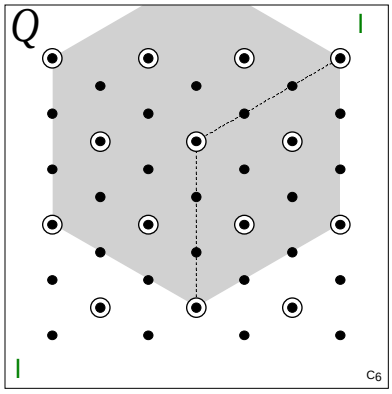


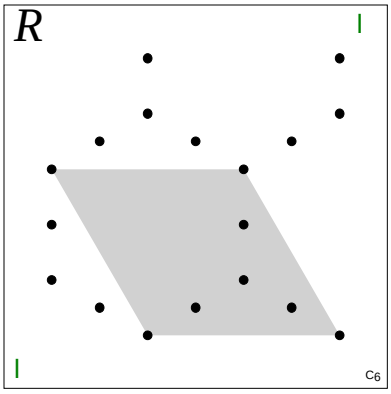


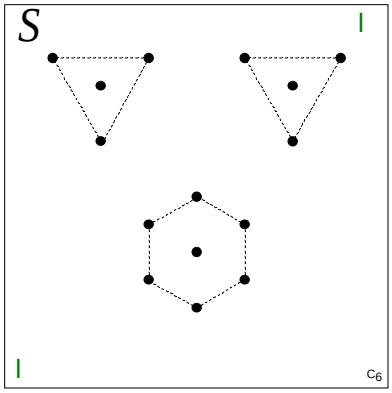


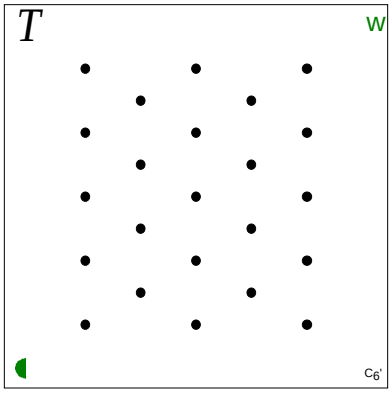
O not included. Use back side of *K*.





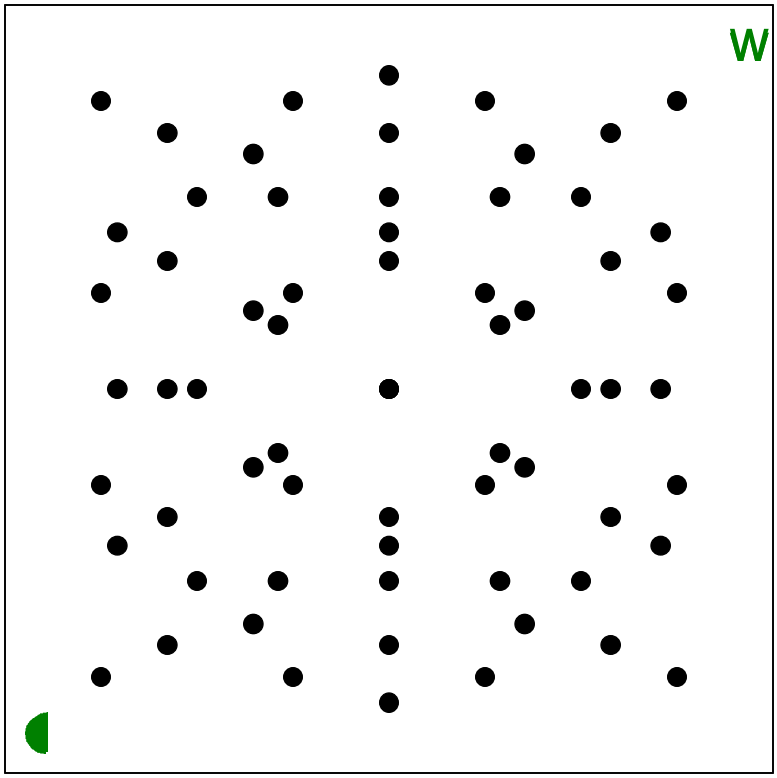


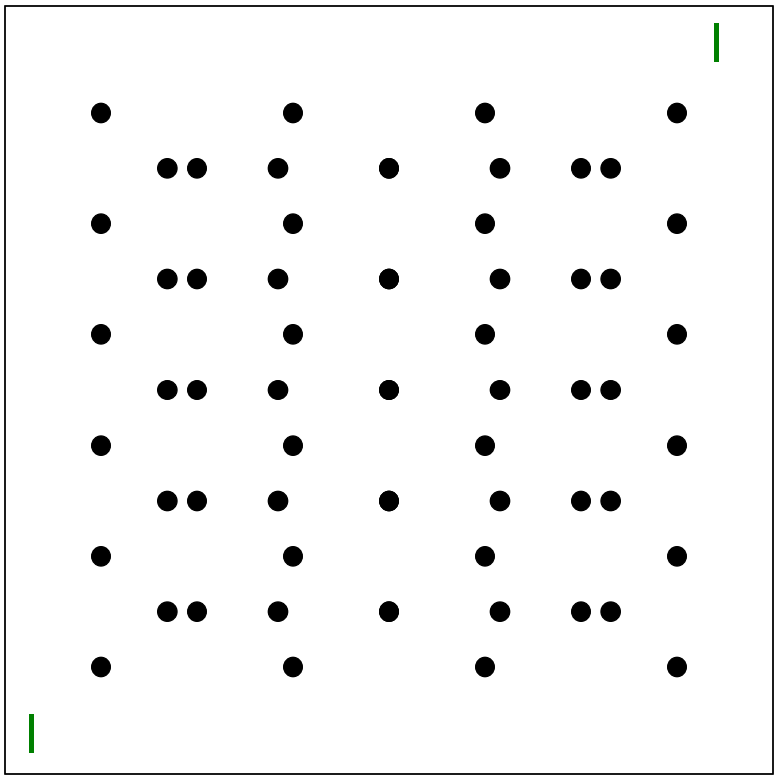




T not included. Use back side of *N*.

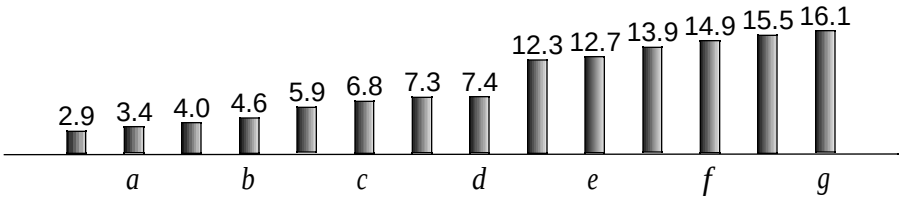
Base Plates

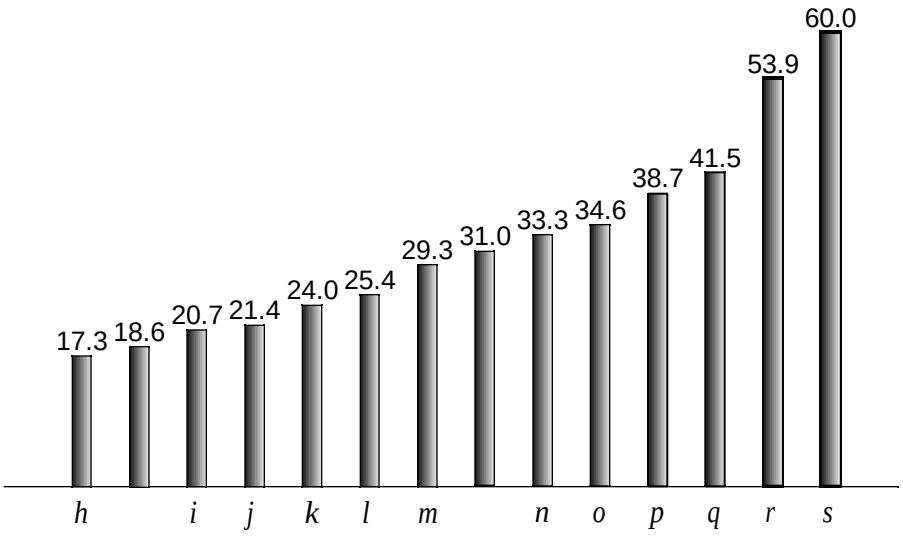


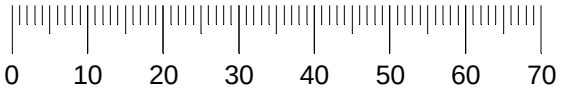


Spacers (actual size, height given in mm)

For compatability with earlier kits, some of the spacers have letter designations.







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