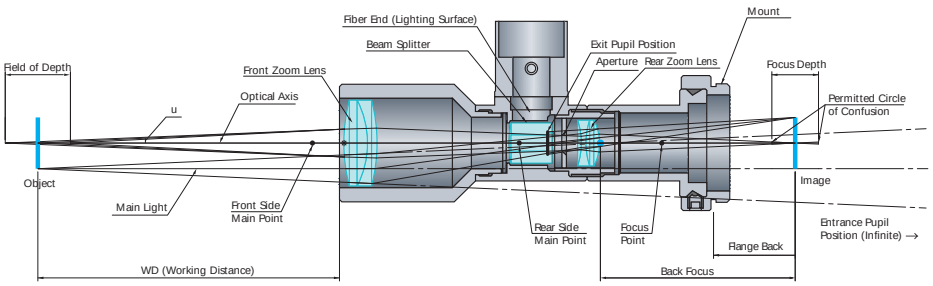
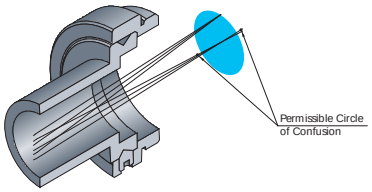
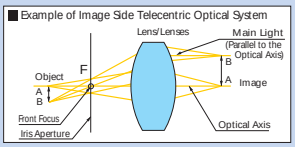
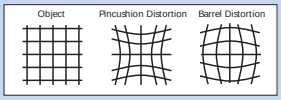
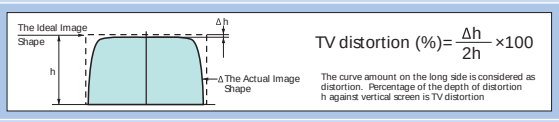
Data and Glossary





*This diagram is intended for the purpose of explaining technology. The positions and distances shown in this diagram are not necessarily accurate.

Performance

Telecentric Optics	An optical system where the principal ray is parallel to the lens optical axis. An optical system where the light comes from an object toward a lens and stays parallel to the optical axis, even outside the axis, is called object side telecentric optics. A system where the light comes from a lens toward an image and stays parallel to the optical axis, even outside the axis, is called image side telecentric optics. Telecentric optics indicated in this catalog are object side telecentric optics. 
Resolution (μm)	Resolution is a measured by how closely 2 points can be before they cannot be distinguished. For example, 1μm resolution means that 2 points that are 1μm away from each other can be distinguished. Resolution values in this catalog are theoretical resolutions for the lenses. The following is a formula to calculate theoretical resolution based on a lens's ray diffraction with no aberration. (Rayleigh formula) $\text{Resolution}=\frac{0.61\times\lambda}{NA}$ λ : Wavelength 0.61: Fixed Number
Resolution (Lines/ mm)	Resolution indicates the number of black and white lines distinguished within 1mm in an image through a black and white grid-like chart lens. Resolution is expressed by lines/ mm. For example, 100 lines/mm means that black and white pitch 1/100mm (10μm) can be distinguished. Width of both the black and white lines is 1/200mm (5μm).
Horizontal TV Resolution (TV lines)	The total number of black and white horizontal stripes in the width, equivalent to the height of the vertical height on a TV monitor screen. The total stripes in the horizontal width would be 3/4, because the ratio of vertical and horizontal length of the screen is usually 3:4. When the horizontal TV resolution is 240TV lines, total stripes in the horizontal width of the TV monitor would be 320 lines. When measuring resolution of a lens, a pair of black and white lines is counted as one line. However, for TV lines, one pair is counted as 2TV lines.
Distortion (%)	Distortion is the aberration of a lens where a straight object outside of the optical axis appears curved. Distortion of a straight line towards the center is called pincushion distortion, while distortion expanding outwards is called barrel distortion 
TV Distortion (%)	Image distortion on a TV monitor. The closer to zero, the better the performance. 
Aperture EfficiencyMarginal Light Quantity (%)	Aperture efficiency indicates the brightness difference between the optical axis of the image formation plane and its surrounding area when an evenly bright object is captured with a lens. It is expressed by percent (%) assuming that the center brightness is 100. It is one of the optical characteristics of a lens. Marginal light quantity in this catalog indicates aperture efficiency.
Shading (%)	Shading is the brightness difference between the center of a TV monitor and its edges when an evenly bright object is captured with a lens and a CCD-TV camera. It is expressed by percent (%). Generally, this percentage is calculated based on power ratio of light receiving elements and CCD elements. Shading indicates comprehensive performance of a lens and TV camera. To make shading smaller, telecentric optics is used.
Chromatic Aberration	In lens optics, positions where images are formed and image magnification differ according to the light's wavelength. Rays of different wavelengths have different colors. This is called chromatic aberration. Aberration on the optical axis is called chromatic aberration on the axis, and magnification difference is called magnification chromatic aberration.

Distance

WD (Working Distance) (mm)

Distance from the front end of a lens system to the object under inspection.

Focal Distance f (mm) Back Focus/ Front Focus

Focal distance is the distance from the optical system's principle point to the focal point. Distance from the vertex of the last lens to the back focal point is called back focus. Distance from the vertex of the first lens to the front focal point is called front focus.

Depth of Field

Depth is the distance between the nearest and farthest points that appear in acceptably sharp focus when an object is shifted back and forth from the best focal point. Depth range of the object side is called depth of field.

Depth of Field = 2 (Permissible Circle of Confusion x Effective F No Magnification^2)

Images through lenses theoretically form as points. Acceptable blur on an acceptably clear image is called the permissible circle of confusion

Depth of Focus

Depth is the distance between the nearest and farthest points that appear in acceptably sharp focus when a CCD is shifted back and forth from the best focal point. Depth range of the image side is called depth of focus.

Flange Back (mm)

Distance from the front of the camera mount plane to the image.

C-Mount Specifications

Name	Standard External Diameter	No. of Screw Threads (for 25.4mm)	Flange Back
U1	25.400mm	32 Threads	17.526mm

Brightness

Numerical Aperture NA, NA'

When the half angle that an object makes on the entrance pupil is u, and refractive index is n, n x sin u is called object side numerical aperture, NA.
When the half angle that an image makes on exit pupil is u', and refractive index is n', n' x sin u' is called image side numerical aperture, NA'.
NAs in this catalog indicate object side numerical apertures. Numerical aperture is an important value that expresses lens resolution and brightness.

$NA=n \times \sin u$ $NA'=n' \times \sin u'$

The higher the NA, the greater the resolution and brightness are of the lens.

F Number F No

The value indicates lens brightness. It is calculated by dividing the focal distance of the lens by its effective diameter (entrance pupil diameter D mm) looking from its object side. It can also be calculated by NA and the lens' optical magnification (β). The smaller the number the brighter the lens is.

$F\ No=f/D$

Effective F No

The value indicates lens brightness when an object is located in finite distance, the value which indicates the brightness when actually operated. The higher the optical magnification (β), the darker the lens is.

Effective $F\ No=\beta/(2 \times NA)=(1 \times NA')$

Effective $F\ No=(1+\beta) \times F\ No$*

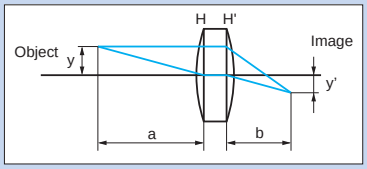
*Approximation for Thin-Walled Systems

Magnification

Optical Magnification β

Image size ratio against the object size.

$\beta = y'/y$
$= b/a$
$= NA/NA'$
= CCD Camera Element Size / Actual Size of Dield of View



Electronic Magnification

Electronic magnification is the magnification of an image on a CCD camera when it is displayed on a monitor screen.

Monitor Magnification

Monitor magnification is the magnification of an object displayed on a monitor screen through a lens.

Monitor Magnification = (Optical Magnification β) x (Electronic Magnification)

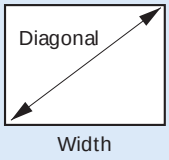
(Calculation Example) Optical Magnification β= 0.2x, CCD Size 1/2" (Diagonal Line 8mm), Monitor 14" :
Electronic Magnification =14 x 25.4 β 8 = 44.45 (Times)
Monitor Magnification = 0.2 x 44.45= 8.89 (Times) (1 Inch = 25.4mm)

Field of View

Field of view is the size of an object that can be shot when the lens is attached to a CCD-TV camera.
The size of field of view is (CCD format size) ÷ (optical magnification β).

(Calculation Example) Optical Magnification β=0.2x, CCD Size 1/2" (4.8mm Long, 6.4mm Wide) :
Size of Field of View Length =4.8/0.2=24 (mm)
Width =6.4/0.2=32 (mm)

Size of CCD Camera Elements



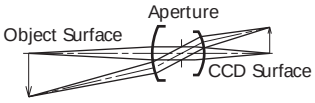
Type	Aspect Ratio	Length mm	Width mm	Diagonal mm
1/6"	4:3	1.73	2.3	2.878
1/4"	4:3	2.4	3.2	4
1/3"	4:3	3.6	4.8	6
1/2"	4:3	4.8	6.4	8
1/1.8"	4:3	5.3	7.2	8.9
2/3"	4:3	6.6	8.8	11
1"	4:3	9.6	12.8	16
4/3"	4:3	13.5	18	22.5

Formula

Resolution (μm)	=	0.61(Fixed Number)×0.55(Design Wavelength)÷NA
Effective F No	=	Magnification / 2NA
Depth of Field (mm)	=	2 (Permissible Circle of Confusion Diameter × Effective F No ÷ Magnifications^2)
Light Flux Diameter (ø)	=	2NA × Height from Object + Size of Field of View (Angle)

Features of Telecentric Optical System

Non-Telecentric Lens



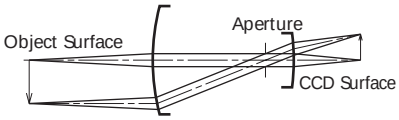
Advantages

Smaller size.
Cost-saving because the number of lenses is fewer.

Disadvantages

Object size or position varies as the object surface moves up and down.

Object Side Telecentric Lens



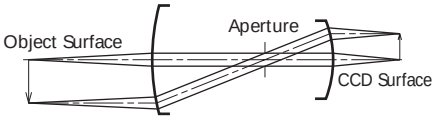
Advantages

Object size does not change even when the object surface moves up and down.
Smaller size is possible when coaxial illumination is used.

Disadvantages

Larger than regular lenses when coaxial illumination is not used.

Double-Sided Telecentric Lens



Advantages

Similar to MML. However, accuracy improves when the size of camera flange back differs greatly.

Disadvantages

Similar to MML. However, higher cost than MML.

Example of Attachment

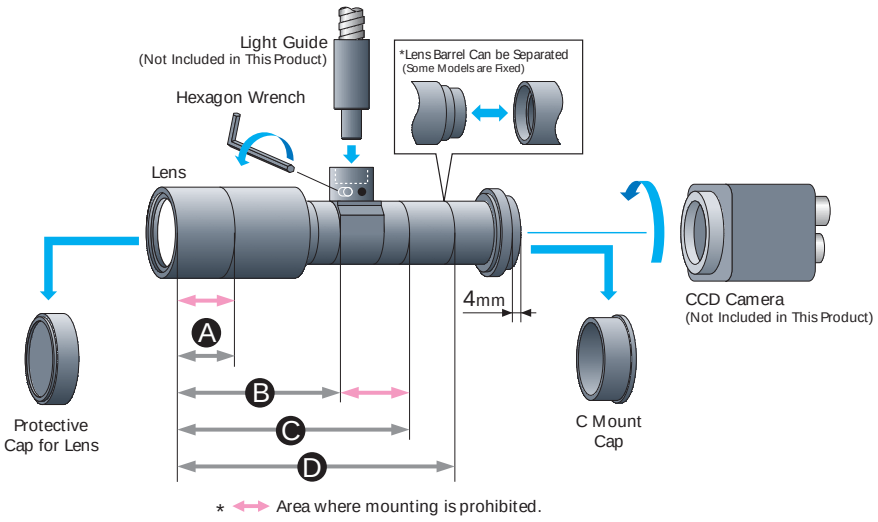


Chart for Positions That Cannot be Held, and That Can be Separated

Model	A	B	C	D
MML-HR 5M Series				
MML03-HR65D-5M	20	68	111	102
MML03-HR65-5M	20	68	111	102
MML05-HR65DVI-5M	10	65	105	—
MML05-HR65VI-5M	10	65	105	—
MML1-HR65DVI-5M	16	36	64	—
MML1-HR65VI-5M	16	36	64	—
MML2-HR65DVI-5M	27	39	68	—
MML2-HR65VI-5M	27	39	68	—
MML3-HR65DVI-5M	10	37	90	—
MML3-HR65VI-5M	10	37	90	—
MML4-HR65DVI-5M	10	37	89	—
MML4-HR65VI-5M	10	37	89	—
MML014-HR110D-5M	20	96	—	—
MML03-HR110D-5M	20	69	114	104
MML03-HR110-5M	20	69	114	104

Model	A	B	C	D
MML-HR Series				
MML05-HR65D	10	25	69	61
MML05-HR65	10	25	69	61
MML08-HR65D	15	35	64	59
MML08-HR65	15	35	64	59
MML1-HR65D	15	33	53	53
MML1-HR65	15	33	53	53
MML1.5-HR65D	11	23	41	44
MML1.5-HR65	11	23	41	44
MML2-HR65D	15	25	46	46
MML2-HR65	15	25	46	46
MML4-HR65D	20	26	47	86
MML4-HR65	20	26	47	86
MML6-HR65D	20	30	47	101
MML6-HR65	20	30	47	101
MML4-HR65D-VI	20	26	58	86
MML6-HR65D-VI	20	30	62	101
MML05-HR110D	11	67	102	93
MML05-HR110	11	67	102	93
MML08-HR110D	20	65	91	82
MML08-HR110	20	65	91	82
MML1-HR110D	30	64	95	81
MML1-HR110	30	64	95	81
MML1.5-HR110D	13	50	76	72
MML1.5-HR110	13	50	76	72
MML2-HR110D	20	43	70	68
MML2-HR110	20	43	70	68
MML4-HR110D	20	44	120	107
MML6-HR110D	15	48	120	110

Model	A	B	C	D
MML-ST Series				
MML1-ST40D	11	17	34	37
MML1-ST40	11	17	34	—
MML1.5-ST40D	10	14	30	34
MML1.5-ST40	10	14	30	—
MML2-ST40D	9	12	27	32
MML2-ST40	9	12	27	—
MML3-ST40D	9	12	27	32
MML3-ST40	9	12	27	—
MML4-ST40D	10	10	27	31
MML4-ST40	10	10	27	—
MML6-ST40D	10	10	27	31
MML6-ST40	10	10	27	—
MML8-ST40D	10	10	27	31
MML8-ST40	10	10	27	—
MML08-ST65D	15	39	62	59
MML08-ST65	15	39	62	59
MML1-ST65D/-CM	15	33	53	53
MML1-ST65/-CM	15	33	53	—
MML1.5-ST65D/-CM	11	23	41	44
MML1.5-ST65/-CM	11	23	41	—
MML2-ST65D	15	25	46	46
MML2-ST65	15	25	46	—
MML2-ST65DS/-CM	20	20	40	40
MML2-ST65S/-CM	20	20	40	—
MML3-ST65DS/-CM	17	17	47	38
MML3-ST65S/-CM	17	17	47	—
MML4-ST65D	20	26	47	85
MML4-ST65	20	26	47	—
MML4-ST65DS/-CM	18	18	34	55
MML4-ST65S/-CM	18	18	34	—
MML6-ST65D	20	30	47	100
MML6-ST65	20	30	47	—
MML6-ST65DS/-CM	18	18	55	55
MML6-ST65S/-CM	18	18	55	—
MML8-ST65DS	18	18	55	55
MML8-ST65S	18	18	55	—
MML08-ST110D	20	65	93	85
MML08-ST110	20	65	93	85
MML1-ST110D	20	50	75	75
MML1-ST110	20	50	75	75
MML2-ST110D	20	44	68	64
MML2-ST110	20	44	68	—
MML2-ST110DS/-CM	12	27	50	48
MML2-ST110S/-CM	12	27	50	—
MML3-ST110DS/-CM	12	27	50	48
MML3-ST110S/-CM	12	27	50	—
MML4-ST110D/-CM	15	29	68	49
MML4-ST110/-CM	15	29	68	—

Model	A	B	C	D
MML6-ST110D/-CM	15	29	68	49
MML6-ST110/-CM	15	29	68	—
MML8-ST110D/-CM	15	29	68	49
MML8-ST110/-CM	15	29	68	—
MML12-ST110D	15	29	68	49
MML1-ST150D	10	74	91	91
MML1-ST150	10	74	91	91
MML08-ST170D	10	74	91	91
MML08-ST170	10	74	91	91
MML1-ST300D	25	100	150	190
MML3-ST300D	23	87	171	—
MML4-ST300D	23	87	171	—

Chart for Field of View

Magnification	Sensor Size											
	2/3"			1/1.8"			1/2"			1/3"		
	Length	Wides	Angle	Length	Wides	Angle	Length	Wides	Angle	Length	Wides	Angle
0.1x	66.00	88.00	110.00	53.19	71.76	89.32	48.00	64.00	80.00	36.00	48.00	60.00
0.14x	47.14	62.86	78.57	37.99	51.26	63.80	34.29	45.71	57.14	25.71	34.29	42.86
0.16x	41.25	55.00	68.75	33.24	44.85	55.83	30.00	40.00	50.00	22.50	30.00	37.50
0.18x	36.67	48.89	61.11	29.55	39.87	49.62	26.67	35.56	44.44	20.00	26.67	33.33
0.2x	33.00	44.00	55.00	26.60	35.88	44.66	24.00	32.00	40.00	18.00	24.00	30.00
0.3x	22.00	29.33	36.67	17.73	23.92	29.77	16.00	21.33	26.67	12.00	16.00	20.00
0.4x	16.50	22.00	27.50	13.30	17.94	22.33	12.00	16.00	20.00	9.00	12.00	15.00
0.5x	13.20	17.60	22.00	10.64	14.35	17.86	9.60	12.80	16.00	7.20	9.60	12.00
0.6x	11.00	14.67	18.33	8.87	11.96	14.89	8.00	10.67	13.33	6.00	8.00	10.00
0.7x	9.43	12.57	15.71	7.60	10.25	12.76	6.86	9.14	11.43	5.14	6.86	8.57
0.75x	8.80	11.73	14.67	7.09	9.57	11.91	6.40	8.53	10.67	4.80	6.40	8.00
0.8x	8.25	11.00	13.75	6.65	8.97	11.17	6.00	8.00	10.00	4.50	6.00	7.50
0.9x	7.33	9.78	12.22	5.91	7.97	9.92	5.33	7.11	8.89	4.00	5.33	6.67
1x	6.60	8.80	11.00	5.32	7.18	8.93	4.80	6.40	8.00	3.60	4.80	6.00
1.5x	4.40	5.87	7.33	3.55	4.78	5.95	3.20	4.27	5.33	2.40	3.20	4.00
2x	3.30	4.40	5.50	2.66	3.59	4.47	2.40	3.20	4.00	1.80	2.40	3.00
2.5x	2.64	3.52	4.40	2.13	2.87	3.57	1.92	2.56	3.20	1.44	1.92	2.40
3x	2.20	2.93	3.67	1.77	2.39	2.98	1.60	2.13	2.67	1.20	1.60	2.00
3.5x	1.89	2.51	3.14	1.52	2.05	2.55	1.37	1.83	2.29	1.03	1.37	1.71
4x	1.65	2.20	2.75	1.33	1.79	2.23	1.20	1.60	2.00	0.90	1.20	1.50
4.5x	1.47	1.96	2.44	1.18	1.59	1.98	1.07	1.42	1.78	0.80	1.07	1.33
5x	1.32	1.76	2.20	1.06	1.44	1.79	0.96	1.28	1.60	0.72	0.96	1.20
6x	1.10	1.47	1.83	0.89	1.20	1.49	0.80	1.07	1.33	0.60	0.80	1.00
7x	0.94	1.26	1.57	0.76	1.03	1.28	0.69	0.91	1.14	0.51	0.69	0.86
8x	0.83	1.10	1.38	0.66	0.90	1.12	0.60	0.80	1.00	0.45	0.60	0.75
9x	0.73	0.98	1.22	0.59	0.80	0.99	0.53	0.71	0.89	0.40	0.53	0.67
10x	0.66	0.88	1.10	0.53	0.72	0.89	0.48	0.64	0.80	0.36	0.48	0.60
11x	0.60	0.80	1.00	0.48	0.65	0.81	0.44	0.58	0.73	0.33	0.44	0.55
12x	0.55	0.73	0.92	0.44	0.60	0.74	0.40	0.53	0.67	0.30	0.40	0.50
15x	0.44	0.59	0.73	0.35	0.48	0.60	0.32	0.43	0.53	0.24	0.32	0.40
20x	0.33	0.44	0.55	0.27	0.36	0.45	0.24	0.32	0.40	0.18	0.24	0.30

Chart for Field of View

Optical Magnification	2/3" (Length x Width x Angle)	Monitor Magnification 9"	Monitor Magnification 14"	1/2" (Length x Width x Angle)	Monitor Magnification 9"	Monitor Magnification 14"	1/3" (Length x Width x Angle)	Monitor Magnification 9"	Monitor Magnification 14"
×0.1	66 × 88 × 110	2.1	3.2	48 × 64 × 80	2.9	4.5	36 × 48 × 60	3.8	5.9
×0.14	47 × 63 × 79	2.9	4.5	34 × 46 × 57	4.0	6.2	26 × 34 × 43	5.3	8.3
×0.16	41 × 55 × 69	3.4	5.2	30 × 40 × 50	4.6	7.1	23 × 30 × 38	6.1	9.5
×0.18	37 × 49 × 61	3.8	5.8	27 × 36 × 44	5.1	8.0	20 × 27 × 33	6.9	10.7
×0.2	33 × 44 × 55	4.2	6.5	24 × 32 × 40	5.7	8.9	18 × 24 × 30	7.6	11.9
×0.3	22 × 29 × 37	6.3	9.7	16 × 21 × 27	8.6	13.4	12 × 16 × 20	11.4	17.8
×0.4	17 × 22 × 28	8.4	12.9	12 × 16 × 20	11.4	17.8	9 × 12 × 15	15.2	23.7
×0.5	13 × 18 × 22	10.5	16.2	9.6 × 12.8 × 16	14.3	22.3	7.2 × 9.6 × 12	19.1	29.7
×0.6	11 × 15 × 18	12.6	19.4	8.0 × 10.7 × 13	17.2	26.7	6 × 8 × 10	22.9	35.6
×0.7	9 × 13 × 16	14.7	22.6	6.9 × 9.1 × 11	20.0	31.2	5.1 × 6.9 × 8.6	26.7	41.5
×0.75	9 × 12 × 15	15.8	24.2	6.4 × 8.5 × 11	21.5	33.4	4.8 × 6.4 × 8.0	28.6	44.5
×0.8	8 × 11 × 14	16.8	25.8	6.0 × 8.0 × 10	22.9	35.6	4.5 × 6.0 × 7.5	30.5	47.4
×0.9	7.3 × 9.8 × 12.2	18.9	29.1	5.3 × 7.1 × 8.9	25.7	40.1	4.0 × 5.3 × 6.7	34.3	53.4
×1	6.6 × 8.8 × 11.0	21.0	32.3	4.8 × 6.4 × 8.0	28.6	44.5	3.6 × 4.8 × 6.0	38.1	59.3
×1.5	4.4 × 5.9 × 7.3	31.5	48.5	3.2 × 4.3 × 5.3	42.9	66.8	2.4 × 3.2 × 4.0	57.2	89.0
×2	3.3 × 4.4 × 5.5	42.0	64.6	2.4 × 3.2 × 4.0	57.2	89.0	1.8 × 2.4 × 3.0	76.2	119
×2.5	2.6 × 3.5 × 4.4	52.5	80.8	1.9 × 2.6 × 3.2	71.5	111	1.4 × 1.9 × 2.4	95.3	148
×3	2.2 × 2.9 × 3.7	63.0	96.9	1.6 × 2.1 × 2.7	85.8	134	1.2 × 1.6 × 2.0	114	178
×3.5	1.9 × 2.5 × 3.1	73.5	113	1.4 × 1.8 × 2.3	100	156	1.0 × 1.4 × 1.7	133	208
×4	1.7 × 2.2 × 2.8	84.0	129	1.2 × 1.6 × 2.0	114	178	0.9 × 1.2 × 1.5	152	237
×4.5	1.5 × 2.0 × 2.4	94.5	145	1.1 × 1.4 × 1.8	129	200	0.8 × 1.1 × 1.3	171	267
×5	1.3 × 1.8 × 2.2	105	162	1.0 × 1.3 × 1.6	143	223	0.7 × 1.0 × 1.2	191	297
×6	1.1 × 1.5 × 1.8	126	194	0.8 × 1.1 × 1.3	172	267	0.6 × 0.8 × 1.0	229	356
×7	0.94 × 1.26 × 1.57	147	226	0.69 × 0.91 × 1.14	200	312	0.51 × 0.69 × 0.86	267	415
×8	0.83 × 1.10 × 1.38	168	258	0.60 × 0.80 × 1.00	229	356	0.45 × 0.60 × 0.75	305	474
×9	0.73 × 0.98 × 1.22	189	291	0.53 × 0.71 × 0.89	257	401	0.40 × 0.53 × 0.67	343	534
×10	0.66 × 0.88 × 1.10	210	323	0.48 × 0.64 × 0.80	286	445	0.36 × 0.48 × 0.60	381	593
×11	0.60 × 0.80 × 1.00	231	355	0.44 × 0.58 × 0.73	315	490	0.33 × 0.44 × 0.55	419	652
×12	0.55 × 0.73 × 0.92	252	388	0.40 × 0.53 × 0.67	343	534	0.30 × 0.40 × 0.50	457	712

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