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<tr>
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<td>1.0</td>
<td>see equation following</td>
</tr>
<tr>
<td>GL_LINEAR_ATTENUATION</td>
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<td></td>
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<tr>
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There are also other parameters which restrict a light to be a spotlight.

**Light color:** GL_AMBIENT, GL_DIFFUSE, GL_SPECULAR
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The fourth value specified for GL_POSITION controls whether the light is directional or positional.
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**Light position: GL_POSITION**

The fourth value specified for GL_POSITION controls whether the light is directional or positional. A directional light is infinitely far away, such that the rays of light it emanates are...
parallel (e.g. like the rays of light from the sun striking a small area on Earth).
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$$\text{attenuation factor} = \frac{1}{k_c + k_i d + k_q d^2}$$
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The attenuation is calculated from the expression

\[
\text{attenuation factor} = \frac{1}{k_c + k_l d + k_q d^2}
\]

where \( d \) is the distance from the light source, and \( k_c, k_l, \) and \( k_q \) are the constant, linear, and quadratic attenuation terms.
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The following simple program light.c shows a lighted sphere:
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/* Initialize material property, light source, * lighting model, and depth buffer. */

void init(void)
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    GLfloat mat_specular[] = { 1.0, 1.0, 1.0, 1.0 };  
    GLfloat mat_shininess[] = { 50.0 }; 
    GLfloat light_position[] = { 1.0, 1.0, 1.0, 0.0 }; 
    GLfloat white_light_[] = { 1.0, 1.0, 1.0, 0.0 };
First example

The following simple program `light.c` shows a lighted sphere:

```c
/* Initialize material property, light source, *
* lighting model, and depth buffer. */
void init(void)
{
    GLfloat mat_specular[] = { 1.0, 1.0, 1.0, 1.0 };  
    GLfloat mat_shininess[] = { 50.0 };            
    GLfloat light_position[] = { 1.0, 1.0, 1.0, 0.0 }; 
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    glClearColor (0.0, 0.0, 0.0, 0.0); 
    glShadeModel (GL_SMOOTH);
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    GLfloat white_light[] = { 1.0, 1.0, 1.0, 0.0 };

    glClearColor (0.0, 0.0, 0.0, 0.0);
    glShadeModel (GL_SMOOTH);

    glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
    glMaterialfv(GL_FRONT, GL_SHININESS, mat_shininess);
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    glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
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    glLightfv(GL_LIGHT0, GL_POSITION, light_position);
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    glShadeModel (GL_SMOOTH); 

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    glMaterialfv(GL_FRONT, GL_SHININESS, mat_shininess); 
    glLightfv(GL_LIGHT0, GL_POSITION, light_position); 
    glLightfv(GL_LIGHT0, GL_DIFFUSE, white_light); 
    glLightfv(GL_LIGHT0, GL_SPECULAR, white_light); 

    glEnable(GL_LIGHTING); 
    glEnable(GL_LIGHT0); 
    glEnable(GL_DEPTH_TEST); }
```
void display(void)
{
    glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glutSolidSphere (1.0, 20, 16);
    glFlush ();
}
void display(void)
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Second example
void display(void)
{
    glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
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    glFlush();
}

Second example

This example, movelight.c, illustrates how the position of a light is transformed by the MODELVIEW matrix:
void display(void)
{
    glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
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void init(void)
{
    glClearColor (0.0, 0.0, 0.0, 0.0);
    glShadeModel (GL_SMOOTH);
    glEnable(GL_LIGHTING);
    glEnable(GL_LIGHT0);
    glEnable(GL_LIGHT1);
    glEnable(GL_DEPTH_TEST);
}
void display(void)
{
    glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glutSolidSphere (1.0, 20, 16);
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This example, movelight.c, illustrates how the position of a light is transformed by the MODELVIEW matrix:

void init(void)
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    glClearColor (0.0, 0.0, 0.0, 0.0);
    glShadeModel (GL_SMOOTH);
    glEnable(GL_LIGHTING);
    glEnable(GL_LIGHT0);
    glEnable(GL_LIGHT1);
    glEnable(GL_DEPTH_TEST);
}
void display(void)
{
    GLfloat position[] = { 0.0, 0.0, 1.5, 1.0 };
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{
    GLfloat position[] = { 0.0, 0.0, 1.5, 1.0 };

    glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glPushMatrix ();
void display(void)
{
    GLfloat position[] = { 0.0, 0.0, 1.5, 1.0 };

    glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glPushMatrix ();

    glPushMatrix ();
    glRotated ((GLdouble) spin, 1.0, 0.0, 0.0);
    glLightfv (GL_LIGHT0, GL_POSITION, position);
    glTranslated (0.0, 0.0, 1.5);
void display(void)
{
    GLfloat position[] = { 0.0, 0.0, 1.5, 1.0 };

    glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glPushMatrix ();

    glPushMatrix ();
    glRotated ((GLfloat) spin, 1.0, 0.0, 0.0);
    glLightfv (GL_LIGHT0, GL_POSITION, position);
    glTranslated (0.0, 0.0, 1.5);
    glDisable (GL_LIGHTING); /* Draw an unlit wire cube at */
    glColor3f (0.0, 1.0, 1.0); /* the position of the light. */
    glutWireCube (0.1);
    glEnable (GL_LIGHTING);
    glPopMatrix ();
}

void display(void)
{
    GLfloat position[] = { 0.0, 0.0, 1.5, 1.0 };
    
    glClear (GL_COLOR_BUFFER_BIT | GL_DEPTH_BUFFER_BIT);
    glPushMatrix ();
    
    glPushMatrix ();
    glRotated ((GLdouble) spin, 1.0, 0.0, 0.0);
    glLightfv (GL_LIGHT0, GL_POSITION, position);
    glTranslated (0.0, 0.0, 1.5);
    
    glBegin (GL_TRIANGLES);
    
    glEnd ();
    
    glDisable (GL_LIGHTING); /* Draw an unlit wire cube at */
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    glutSolidTorus (0.275, 0.85, 8, 15);
}
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}
void reshape (int w, int h)
{
    glViewport (0, 0, (GLsizei) w, (GLsizei) h);
    glMatrixMode (GL_PROJECTION);
    glLoadIdentity();
    gluPerspective (40.0, (GLfloat) w/(GLfloat) h, 1.0, 20.0);
    glMatrixMode (GL_MODELVIEW);
    glLoadIdentity();
    gluLookAt (0.0, 0.0, 5.0, 0.0, 0.0, 0.0, 0.0, 1.0, 0.0);
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}

void mouse(int button, int state, int x, int y) {
    switch (button) {
    case GLUT_LEFT_BUTTON:
        if (state == GLUT_DOWN) {
            spin = (spin + 30) % 360;
            glutPostRedisplay();
        }
        break;
    default:
        break;
    }
}
void keyboard(unsigned char key, int x, int y) {
    switch (key) {
    case 27:
        exit(0);
        break;
    }
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    switch (key) {
    case 27:
        exit(0);
        break;
    }
}

int main(int argc, char** argv)
{
    glutInit(&argc, argv);
    glutInitDisplayMode (GLUT_SINGLE | GLUT_RGB | GLUT_DEPTH);
    glutInitWindowSize (500, 500);
    glutInitWindowPosition (100, 100);
    glutCreateWindow (argv[0]);
    init ();
    glutDisplayFunc(display);
    glutReshapeFunc(reshape);
    glutMouseFunc(mouse);
    glutKeyboardFunc(keyboard);
    glutMainLoop();
    return 0;
}
Material properties
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The colors of light reflected by a primitive are set with the function `glMaterial*()`.
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\begin{verbatim}
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The tutorial `lightmaterial` shows interaction between light sources and material properties.
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void glLightModel{if}(GLenum pname, TYPE param);
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void glLightModeli(GLenum pname, TYPE param);
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void glLightModel{if}(GLenum pname, TYPE param);
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```

Again, `pname` specifies the property; `param` specifies the set of parameters for the property `pname`. 
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void glLightModelf(GLenum pname, TYPE param);
void glLightModelfv(GLenum pname, TYPE *param);
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Again, `pname` specifies the property; `param` specifies the set of parameters for the property `pname`.

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All those properties can be set individually with the function `glLightModel*()`.

```c
void glLightModelif(GLenum pname, TYPE param);
void glLightModelifv(GLenum pname, TYPE *param);
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Again, `pname` specifies the property; `param` specifies the set of parameters for the property `pname`.

In the following, `GL_LIGHT_MODEL` precedes the parameter name:
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<tr>
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\text{ambient}_{\text{light model}} \times \text{ambient}_{\text{material}} + \\
\sum_{i=0}^{n-1} \left( \frac{1}{k_e + k_d + k_q d^2} \right) \times (\text{spotlight effect})_i \times \\
[\text{ambient}_{\text{light}} \times \text{ambient}_{\text{material}} + \\
(\max\{L_i \cdot n, 0\}) \times \text{diffuse}_{\text{light}} \times \text{diffuse}_{\text{material}} + \\
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where \(n = (n_x, n_y, n_z)\) is the unit normal vector at the vertex and \(L = (L_x, L_y, L_z)\) is the unit vector pointing from the vertex to the light.
How a vertex’s color is calculated in OpenGL

The color of a vertex under lighting in OpenGL is:

\[
\text{color} = \text{emission at the vertex} + \\
global \text{ ambient light scaled by the ambient coefficient of the material} + \\
\text{the ambient, diffuse, and specular components from all light sources, properly attenuated}
\]

The contribution from individual light sources is calculated as follows:

\[
\text{color} = \text{emission}_{\text{material}} + \\
\text{ambient}_{\text{light model}} \ast \text{ambient}_{\text{material}} + \\
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The contribution from individual light sources is calculated as follows:

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\text{color} = \text{emission}_{\text{material}} + \\
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\sum_{i=0}^{n-1} \left( \frac{1}{k_c + k_id + k_qd^2} \right) * \text{(spotlight effect)}_i * \\
[\text{ambient}_{\text{light}} * \text{ambient}_{\text{material}} + \\
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The diffuse light source illuminates the right polygon much more than the left, and the transition in illumination is abrupt.
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These two modes can be toggled by pressing ‘t’. Additionally, a white specular component can be added to the light source by pressing ‘s’.

The following is the most relevant code from `tent.c`...
void display(void) {

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    /* We require unit length normal vectors. For a vector with 2 non-zero
    * elements of equal magnitude, the magnitude of both elements should be equal
    * to 1 / sqrt(2) = 0.7071 for the vector to be of unit length. */
    double l = 0.7071;
void display(void) {
    
    /* We require unit length normal vectors. For a vector with 2 non-zero
    * elements of equal magnitude, the magnitude of both elements should be equal
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    double l = 0.7071;

    /* Set up the light in a position perpendicular to the right polygon. */
    GLfloat light_position[] = { 3.0, 2.0, 0.0, 1.0};
    glLightfv(GL_LIGHT0, GL_POSITION, light_position);
void display(void) {
    
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    /* Set up the light in a position perpendicular to the right polygon. */
    GLfloat light_position[] = { 3.0, 2.0, 0.0, 1.0 };  
    glLightfv(GL_LIGHT0, GL_POSITION, light_position);

    /* Draw the tent. */
    glBegin(GL_QUADS);
void display(void) {
    .
    .
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     * elements of equal magnitude, the magnitude of both elements should be equal
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    .
    .
    .

    /* Draw the tent. */
    glBegin(GL_QUADS);
    /* Left side. */
void display(void) {
    .
    .
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    /* Draw the tent. */
    glBegin(GL_QUADS);
    /* Left side. */
    glNormal3f(-l, l, 0);
void display(void) {

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    /* Draw the tent. */
    glBegin(GL_QUADS);
    /* Left side. */
        glNormal3f(-1, 1, 0);
        glVertex3f(0, 0, 0);
void display(void) {
  
  
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  double l = 0.7071;
  
  /* Set up the light in a position perpendicular to the right polygon. */
  GLfloat light_position[] = { 3.0, 2.0, 0.0, 1.0 }; // Filled with my new value
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/* Right side. */
void display(void) {
    
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    /* Right side. */
    glNormal3f(l, l, 0);
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    /* to 1 / sqrt(2) = 0.7071 for the vector to be of unit length. */
    double l = 0.7071;

    /* Set up the light in a position perpendicular to the right polygon. */
    GLfloat light_position[] = { 3.0, 2.0, 0.0, 1.0 };  
    glLightfv(GL_LIGHT0, GL_POSITION, light_position);

    /* Draw the tent. */
    glBegin(GL_QUADS);
    /* Left side. */
    glNormal3f(-l, l, 0);
    glVertex3f(0, 0, 0);
    glVertex3f(0, 0, 1);
    if (topUp) glNormal3f(0, 1, 0);
    glVertex3f(1, 1, 1);
    glVertex3f(1, 1, 0);
    /* Right side. */
    glNormal3f(l, l, 0);
    glVertex3f(2, 0, 1);
    glVertex3f(2, 0, 0);
    if (topUp) glNormal3f(0, 1, 0);
    glVertex3f(1, 1, 0);
    glEnd();
}
void display(void) {
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     * elements of equal magnitude, the magnitude of both elements should be equal
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    glVertex3f(2, 0, 1);
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   glVertex3f(1, 1, 0);
   glVertex3f(1, 1, 1);
  glEnd();
void display(void) {
    
    
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    glVertex3f(1, 1, 0);
    /* Right side. */
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    glVertex3f(2, 0, 1);
    glVertex3f(2, 0, 0);
    if (topUp) glNormal3f(0, 1, 0);
    glVertex3f(1, 1, 0);
    glVertex3f(1, 1, 1);
    glEnd();
    
    
}
void init (void)
{
    glClearColor (0.0, 0.0, 0.0, 0.0);
    glShadeModel (GL_SMOOTH);

    /* Set up material properties. */
    GLfloat mat_ambient[] = { 1.0, 0.0, 0.0, 1.0 };
    GLfloat mat_diffuse[] = { 0.0, 1.0, 0.0, 1.0 };
    glMaterialfv(GL_FRONT, GL_AMBIENT, mat_ambient);
    glMaterialfv(GL_FRONT, GL_DIFFUSE, mat_diffuse);
    glMaterialf(GL_FRONT, GL_SHININESS, 50.0 ); /* No effect if specular == 0 */
    glEnable(GL_LIGHTING);
    glEnable(GL_LIGHT0);
    glEnable(GL_DEPTH_TEST);
}
void key( unsigned char k, int x, int y )
{
    switch (k) {
    case 27: /* Escape */
        exit(0);
        break;
    case 's':
        specular = !specular;
        if ( specular ) {
            GLfloat mat_specular[] = { 0.0, 0.0, 1.0, 1.0 };
            glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
        } else {
            GLfloat mat_specular[] = { 0.0, 0.0, 0.0, 1.0 };
            glMaterialfv(GL_FRONT, GL_SPECULAR, mat_specular);
        }
        break;
    case 't':
        topUp = !topUp;
        break;
    default:
        return;
    }
    glutPostRedisplay();
}