Bending of light

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Photons do not feel the force of gravity. Particles feel the force of gravity because gravitational potential drains part of the particle's self energy from its electric fields. If the particle is in free fall, the lost energy is transferred into kinetic energy within the magnetic fields generated by the particle's motion. A photon is all kinetic energy stored equally in electric and magnetic fields and it is always in free fall. Any liberated energy is passed straight back into its fields as kinetic energy so it neither looses nor gains energy with changing gravitational potential.

Photons are not point like objects but have a width. Newton's original analysis for a "corpuscle" of light passing through the boundary between two media of different refractive index applies equally to photons. The same theory has been developed for media of variable refractive index. The same analysis applies to light in a gravitational field. It is well established in optics that Newton's corpuscular theory and Huygens' wave theory are equivalent. We can therefore apply the following analysis for photons to radio waves.

The speed of light through Euclidean space is affected by gravitational potential:

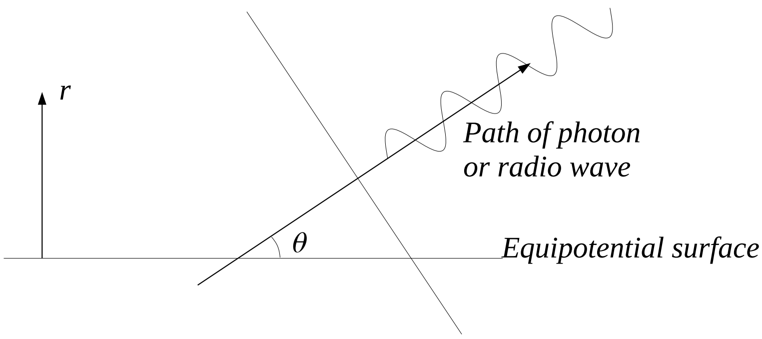
$$c_\Phi = e^{2\frac{\Phi}{c^2}} c$$

We consider a photon or radio wave travelling at an angle θ to the equipotential surfaces and in particular the velocity gradient across a plane perpendicular to its path. This is obviously $\cos\theta \frac{d}{dr}c$.

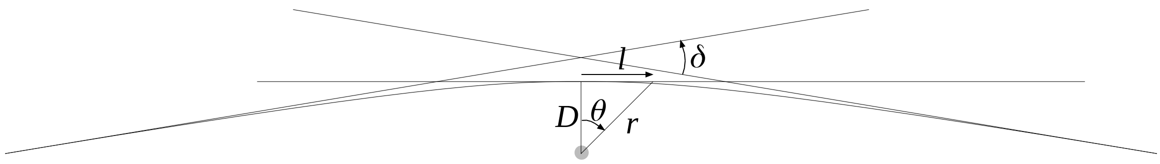
$$\frac{d}{dr}c_\Phi = \frac{d}{dr}e^{2\frac{\Phi}{c^2}} c = \frac{2}{c^2}e^{2\frac{\Phi}{c^2}} c \frac{d}{dr}\frac{-GM}{r} = \frac{2}{c}e^{2\frac{\Phi}{c^2}}\frac{GM}{r^2}$$

Now $e^{2\frac{\Phi}{c^2}} \cong 1$ and $\frac{GM}{r^2} = g$, the acceleration due to gravity, so the velocity gradient is $\frac{d}{dr}c_\Phi = \frac{2g}{c}$ and the velocity gradient across the plane perpendicular to its path is:

$$\frac{dc}{dr} = \frac{2g}{c}\cos\theta$$



If we consider for one moment a spinning disk, the velocity of a point on the disk is ωr and the velocity gradient is $\frac{d}{dr}\omega r = \omega$. The velocity gradient across a photon or wave front is therefore equivalent to the curvature of its path and an angular velocity of the direction of its path.



It is customary to integrate this over the length of the path of a light ray passing a gravitational source at a closest distance D. This is done most simply by expressing everything in terms of D and θ, integrating from 0 to $\frac{\pi}{2}$ and doubling the result. Note that we need to change the rate of change of direction with time $\frac{d\delta}{dt}$ into a rate of change with path length using $\frac{d\delta}{dt} = \frac{1}{c}\frac{d\delta}{dl}$.

$$l = D\tan\theta \qquad \frac{d\delta}{dt} = \frac{1}{c}\frac{d\delta}{dl} \qquad dl = D\sec^2\theta\, d\theta \qquad r = D\sec\theta$$

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$$\delta \;=\; 2\,\frac{2}{c}\int_0^{\infty}\;\frac{GM}{r^2}\,cos\,\theta\,\frac{1}{c}\,dl \;\;=\;\; \frac{4\,G\,M}{c^2}\;\int_0^{\frac{\pi}{2}}\;\frac{D\,sec^2\,\theta}{(D\,sec\,\theta)^2}\,cos\,\theta\,d\theta \;=\; \frac{4\,G\,M}{c^2\,D}\;\int_0^{\frac{\pi}{2}} cos\,\theta\,d\theta$$

$$\delta \;=\; \frac{4\,G\,M}{c^2\,D}$$

Light passing within a distance *D* of a star of mass *M* will be deflected through an angle of $\frac{4\,G\,M}{c^2\,D}$ radians

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