Appendix A

Differential Operators in Cartesian, Cylindrical and Spherical Coordinates
### APPENDIX A. Differential Operators in Cartesian, Cylindrical and Spherical Coordinates

<table>
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<th>Cartesian coordinates</th>
<th>Cylindrical coordinates</th>
<th>Spherical coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\vec{\nabla} \cdot \vec{A})</td>
<td>( \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z} )</td>
<td>( \frac{1}{r} \frac{\partial}{\partial r} \left( r A_r \right) + \frac{1}{r} \frac{\partial A_\theta}{\partial \theta} + \frac{1}{r \sin \theta} \frac{\partial A_\phi}{\partial \phi} )</td>
<td>( \frac{1}{r} \frac{\partial}{\partial r} \left( r^2 A_r \right) + \frac{1}{r \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta A_\theta \right) + \frac{1}{r \sin \theta \sin \phi} \frac{\partial A_\phi}{\partial \phi} )</td>
</tr>
<tr>
<td>( \vec{\nabla} \times \vec{A} )</td>
<td>( \begin{vmatrix} \hat{i} &amp; \hat{j} &amp; \hat{k} \ \frac{\partial}{\partial x} &amp; \frac{\partial}{\partial y} &amp; \frac{\partial}{\partial z} \ A_x &amp; A_y &amp; A_z \end{vmatrix} )</td>
<td>( \begin{vmatrix} \hat{r} &amp; \hat{\theta} &amp; \hat{\phi} \ \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial}{\partial \theta} &amp; \sin \theta \frac{\partial}{\partial \phi} \ \frac{1}{r \sin \theta} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial}{\partial \theta} &amp; \cos \theta \frac{\partial}{\partial \phi} \end{vmatrix} )</td>
<td>( \begin{vmatrix} \hat{r} &amp; \hat{\theta} &amp; \hat{\phi} \ \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial}{\partial \theta} &amp; \frac{1}{r \sin \theta} \frac{\partial}{\partial \phi} \ \frac{1}{r^2} \frac{\partial^2}{\partial \phi^2} &amp; \frac{1}{r} \frac{\partial}{\partial \theta} &amp; \frac{1}{r^2} \frac{\partial}{\partial \phi} \end{vmatrix} )</td>
</tr>
<tr>
<td>( (\vec{\nabla} \cdot \vec{\nabla}) \vec{A} )</td>
<td>( \begin{vmatrix} \frac{\partial^2}{\partial x^2} &amp; \frac{\partial^2}{\partial y^2} &amp; \frac{\partial^2}{\partial z^2} \ \frac{\partial}{\partial x} &amp; \frac{\partial}{\partial y} &amp; \frac{\partial}{\partial z} \ \frac{\partial}{\partial x} &amp; \frac{\partial}{\partial y} &amp; \frac{\partial}{\partial z} \end{vmatrix} )</td>
<td>( \begin{vmatrix} \frac{1}{r^2} \frac{\partial^2}{\partial r^2} &amp; \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r^2} \frac{\partial}{\partial \theta} \ \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial^2}{\partial \theta^2} &amp; \frac{1}{r \sin \theta} \frac{\partial}{\partial \phi} \ \frac{1}{r^2} \frac{\partial}{\partial \theta} &amp; \frac{1}{r \sin \theta} \frac{\partial}{\partial \phi} &amp; \frac{1}{r^2} \frac{\partial^2}{\partial \phi^2} \end{vmatrix} )</td>
<td>( \begin{vmatrix} \frac{1}{r^2} \frac{\partial^2}{\partial r^2} &amp; \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r^2} \frac{1}{\sin \theta} \frac{\partial}{\partial \theta} \ \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial^2}{\partial \theta^2} &amp; \frac{1}{r} \frac{\partial}{\partial \phi} \ \frac{1}{r^2} \frac{\partial}{\partial \theta} &amp; \frac{1}{r \sin \theta} \frac{\partial}{\partial \phi} &amp; \frac{1}{r^2} \frac{\partial^2}{\partial \phi^2} \end{vmatrix} )</td>
</tr>
<tr>
<td>( \vec{\nabla} \times \vec{\nabla} \times \vec{A} )</td>
<td>( \begin{vmatrix} \hat{i} &amp; \hat{j} &amp; \hat{k} \ \frac{\partial}{\partial x} &amp; \frac{\partial}{\partial y} &amp; \frac{\partial}{\partial z} \ \frac{\partial}{\partial x} &amp; \frac{\partial}{\partial y} &amp; \frac{\partial}{\partial z} \end{vmatrix} )</td>
<td>( \begin{vmatrix} \hat{r} &amp; \hat{\theta} &amp; \hat{\phi} \ \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial}{\partial \theta} &amp; \frac{1}{r \sin \theta} \frac{\partial}{\partial \phi} \ \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial}{\partial \theta} &amp; \frac{1}{r \sin \theta} \frac{\partial}{\partial \phi} \end{vmatrix} )</td>
<td>( \begin{vmatrix} \hat{r} &amp; \hat{\theta} &amp; \hat{\phi} \ \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial}{\partial \theta} &amp; \frac{1}{r \sin \theta} \frac{\partial}{\partial \phi} \ \frac{1}{r} \frac{\partial}{\partial r} &amp; \frac{1}{r} \frac{\partial}{\partial \theta} &amp; \frac{1}{r \sin \theta} \frac{\partial}{\partial \phi} \end{vmatrix} )</td>
</tr>
<tr>
<td>( \vec{v}^2 \vec{A} )</td>
<td>( \left[ \frac{\beta \vec{A}}{\beta x} + \frac{\beta \vec{A}}{\beta y} + \frac{\beta \vec{A}}{\beta z} \right] \vec{x} )</td>
<td>( \left[ \frac{1}{r} \left( \frac{1}{r^2} \vec{A} \right) \right] \vec{r} )</td>
<td>( \left[ \frac{1}{r} \left( \frac{1}{r^2} \vec{A} \right) \right] \vec{r} )</td>
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<tr>
<td>( \vec{c} \cdot \vec{v} \vec{A} )</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{x} )</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{y} )</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{z} )</td>
</tr>
<tr>
<td>( \pi ) (T: ( \vec{v} \vec{A} ))</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{x} )</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{y} )</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{z} )</td>
</tr>
<tr>
<td>( \vec{v} \vec{f} )</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{x} )</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{y} )</td>
<td>( \left( \frac{\vec{A}_x}{\beta x} + \frac{\vec{A}_y}{\beta y} + \frac{\vec{A}_z}{\beta z} \right) \vec{z} )</td>
</tr>
</tbody>
</table>
(1) \[ \mathbf{A} \times \mathbf{B} \cdot \mathbf{C} = \mathbf{A} \cdot \mathbf{B} \times \mathbf{C} \]

(2) \[ \mathbf{A} \times (\mathbf{B} \times \mathbf{C}) = \mathbf{B}(\mathbf{A} \cdot \mathbf{C}) - \mathbf{C}(\mathbf{A} \cdot \mathbf{B}) \]

(3) \[ \nabla(\phi + \psi) = \nabla\phi + \nabla\psi \]

(4) \[ \nabla \cdot (\mathbf{A} + \mathbf{B}) = \nabla \cdot \mathbf{A} + \mathbf{B} \cdot \mathbf{B} \]

(5) \[ \nabla \times (\mathbf{A} + \mathbf{B}) = \nabla \times \mathbf{A} + \mathbf{B} \times \mathbf{B} \]

(6) \[ \nabla(\phi\psi) = \phi\nabla\psi + \psi\nabla\phi \]

(7) \[ \nabla \cdot (\psi\mathbf{A}) = \mathbf{A} \cdot \nabla\psi + \psi\nabla \mathbf{A} \]

(8) \[ \nabla \cdot (\mathbf{A} \times \mathbf{B}) = \mathbf{B} \cdot \nabla \times \mathbf{A} - \mathbf{A} \cdot \nabla \times \mathbf{B} \]

(9) \[ \nabla \cdot \nabla\phi = \nabla^2\phi \]

(10) \[ \nabla \times \mathbf{A} = 0 \]

(11) \[ \nabla \times \nabla\phi = 0 \]

(12) \[ \nabla \times (\nabla \times \mathbf{A}) = \nabla(\nabla \cdot \mathbf{A}) - \nabla^2\mathbf{A} \]

(13) \[ (\nabla \times \mathbf{A}) \times \mathbf{A} = (\mathbf{A} \cdot \nabla)\mathbf{A} - 1/2 \nabla(\mathbf{A} \cdot \mathbf{A}) \]

(14) \[ \nabla(\mathbf{A} \cdot \mathbf{B}) = (\mathbf{A} \cdot \nabla)\mathbf{B} + (\mathbf{B} \cdot \nabla)\mathbf{A} + \mathbf{A} \times (\nabla \times \mathbf{B}) + \mathbf{B} \times (\nabla \times \mathbf{A}) \]

(15) \[ \nabla \times (\phi\mathbf{A}) = \phi\nabla \times \mathbf{A} + \nabla\phi \times \mathbf{A} \]

(16) \[ \nabla \times (\mathbf{A} \times \mathbf{B}) = \mathbf{A}(\nabla \cdot \mathbf{B}) - \mathbf{B}(\nabla \cdot \mathbf{A}) + (\mathbf{B} \cdot \nabla)\mathbf{A} - (\mathbf{A} \cdot \nabla)\mathbf{B} \]
Films
Developed for educational purposes with the support of the National Science Foundation at the Education Development Center, films cited fall in one of two series.

Produced by the National Committee for Fluid Mechanics Films and distributed by Encyclopedia Britannica Educational Corp., 425 N. Michigan Ave., Chicago, Illinois (60611) are:

1) Channel Flow of a Compressible Fluid
2) Current-induced Instability of a Mercury Jet
3) Eulerian and Lagrangian Descriptions in Fluid Mechanics
4) Flow Instabilities
5) Fundamentals of Boundary Layers
6) Low-Reynolds Number Flows
7) Magnetohydrodynamics
8) Pressure Fields and Fluid Acceleration
9) Surface Tension and Fluid Mechanics
10) Waves in Fluids

Produced by the National Committee for Electrical Engineering Films and distributed by Education Development Center, 39 Chapel Street, Newton, Mass. 02160 are:

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12) Electric Fields and Moving Media
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