5.

Given: 1) $\lim_{x \to c} f(x) = L$ **Prove:** $L = M$

2) $\lim_{x \to c} f(x) = M$

PROOF:

(By contradiction) Assume $L \neq M$ and try to show that this leads to a contradiction of something known to be true. Since we assume $L \neq M$ then either $L < M$ or $M < L$ and either one of these would imply $|L - M| > 0$ and $\frac{|L-M|}{2} > 0$.

Since $\frac{|L-M|}{2} > 0$ and we were given $\lim_{x \to c} f(x) = L$ there exists **<u>by the definition of limit</u>** $\delta_1 > 0$ such that

$$0 < |x - c| < \delta_1 \Rightarrow |f(x) - L| < \frac{|L-M|}{2}, \tag{1.1}$$

and as we were given $\lim_{x \to c} g(x) = M$ there also exists **<u>by the definition of limit</u>** $\delta_2 > 0$ such that

$$0 < |x - c| < \delta_2 \Rightarrow |f(x) - M| < \frac{|L-M|}{2} \tag{1.2}$$

Setting $\delta = \min(\delta_1, \delta_2)$ then by definition of *min*

$$\delta \leq \delta_1 \quad \& \quad \delta \leq \delta_2 \quad ,$$

and using(1.1) and (1.2) we have also

$$0 < |x - c| < \delta \Rightarrow |f(x) - L| < \frac{|L-M|}{2} \tag{1.3}$$

and

$$0 < |x - c| < \delta \Rightarrow |f(x) - M| < \frac{|L-M|}{2}. \tag{1.4}$$

Now using (1.3) and (1.4) for any x in the set $0 < |x - c| < \delta$

$$\begin{aligned}
|L - M| &= |L + 0 - M| \\
&= |L - f(x) + f(x) - M| \\
&\leq |L - f(x)| + |f(x) - M| && \text{as } |a + b| \leq |a| + |b| \\
&\leq |f(x) - L| + |f(x) - M| && \text{as } |a - b| = |b - a| \\
&< \frac{|L-M|}{2} + \frac{|L-M|}{2} && \text{using } (1.3)\,\&\,(1.4) \\
&= |L - M|
\end{aligned}$$

Carefully following the equalities and inequalities backwards we see that the last statement just showed that

$$|L-M|<|L-M|$$

which clearly is not true and represents a contradiction. This means that a statement we assumed to be true (that was not part of the givens) is false. However the only such assumption was that $L \neq M$ thus $L = M$. $\square$

6.

Given: 1) $\lim_{x\to c} f(x) = L$ 2) $L \neq 0$ 3) $\lim_{x\to c} g(x) = 0$	**Prove:** $\lim_{x\to c} \frac{f(x)}{g(x)}$ *D.N.E.*

PROOF:

(By contradiction) Assume $\lim_{x\to c} \frac{f(x)}{g(x)}$ DOES EXIST and show that leads to a contradiction. If $\lim_{x\to c} \frac{f(x)}{g(x)}$ DOES EXIST then $\lim_{x\to c} \frac{f(x)}{g(x)} = M$ where $M \in \mathbb{R}$. Then since $\lim_{x\to c} \frac{f(x)}{g(x)}$ exists and the $\lim_{x\to c} g(x)$ exists

$$\lim_{x\to c}\left(\frac{f(x)}{g(x)}g(x)\right) = \lim_{x\to c}\frac{f(x)}{g(x)}\lim_{x\to c} g(x) = M\cdot 0 = 0.$$

BUT it is also true that

$$\lim_{x\to c}\left(\frac{f(x)}{g(x)}g(x)\right) = \lim_{x\to c} f(x) = L$$

using the last two equations we see

$$L = \lim_{x\to c}\left(\frac{f(x)}{g(x)}g(x)\right) = 0.$$

which implies $L = 0$ which contradicts $L \neq 0$ (given2). This means that a statement we assumed to be true (that was not part of the givens) is false. However the only such assumption was that $\lim_{x\to c} \frac{f(x)}{g(x)}$ DOES EXIST thus $\lim_{x\to c} \frac{f(x)}{g(x)}$ DOES NOT EXIST.

$\square$

7.

Given: 1) f is continuous at c 2) g is continuous at $f(c)$ 3) $h(x) = g(f(x))$	**Prove:** h is continuous at c

PROOF:

Since g is continuous at $f(c)$ **by definition of continuity**

$$\lim_{y \to f(c)} g(y) = g(f(c)),$$

so if $\varepsilon > 0$, there exists $\delta_1 > 0$ such that

$$|y - f(c)| < \delta_1 \;\Rightarrow |g(y) - f(g(c))| < \varepsilon, \tag{1.5}$$

or stating (1.5) with interval notation,

$$y \in \left(f(c) - \delta_1, f(c) + \delta_1 \right) \;\Rightarrow g(y) \in \left(f\left(g(c)\right) - \varepsilon, f\left(g(c)\right) + \varepsilon \right). \tag{1.6}$$

Since f is continuous at c then **by definition of continuity**

$$\lim_{x \to c} f(x) = f(c),$$

and for the $\delta_1 > 0$ in (1.5) there exists $\delta > 0$ such that

$$\begin{aligned} |x - c| < \delta \;&\Rightarrow \left| f(x) - f(c) \right| < \delta_1 \\ &\Rightarrow f(x) \in \left(f(c) - \delta_1, f(c) + \delta_1 \right) \end{aligned}. \tag{1.7}$$

and using (1.6) substituting $f(x)$ for y we see that,

$$\begin{aligned} &\Rightarrow g\left(f(x) \right) \in \left(f\left(g(c)\right) - \varepsilon, f\left(g(c)\right) + \varepsilon \right) \\ &\Rightarrow \left| g\left(f(x) \right) - f(g(c)) \right| < \varepsilon \\ &\Rightarrow |h(x) - h(c)| < \varepsilon \end{aligned} \tag{1.8}$$

where h was defined by the third given. Following the implies symbols through (1.7) and (1.8) we have that

$$|x - c| < \delta \;\Rightarrow |h(x) - h(c)| < \varepsilon. \tag{1.9}$$

which is equivalent to showing

$$\lim_{x \to c} h(x) = h(c). \tag{1.10}$$

Proving that h is continuous at c.

□