

1 Propositional Practice

Convert the following English sentences into propositional logic and the following propositions into English. State whether or not each statement is true with brief justification.

- (a) There is a real number which is not rational.
- (b) All integers are natural numbers or are negative, but not both.
- (c) If a natural number is divisible by 6, it is divisible by 2 or it is divisible by 3.
- (d) $(\forall x \in \mathbb{Z}) (x \in \mathbb{Q})$
- (e) $(\forall x \in \mathbb{Z}) (((2 \mid x) \vee (3 \mid x)) \implies (6 \mid x))$
- (f) $(\forall x \in \mathbb{N}) ((x > 7) \implies ((\exists a, b \in \mathbb{N}) (a + b = x)))$

Solution:

- (a) $(\exists x \in \mathbb{R}) (x \notin \mathbb{Q})$, or equivalently $(\exists x \in \mathbb{R}) \neg(x \in \mathbb{Q})$. This is true, and we can use π as an example to prove it.
- (b) $(\forall x \in \mathbb{Z}) (((x \in \mathbb{N}) \vee (x < 0)) \wedge \neg((x \in \mathbb{N}) \wedge (x < 0)))$. This is true, since we define the naturals to contain all integers which are not negative.
- (c) $(\forall x \in \mathbb{N}) ((6 \mid x) \implies ((2 \mid x) \vee (3 \mid x)))$. This is true, since any number divisible by 6 can be written as $6k = (2 \cdot 3)k = 2(3k)$, meaning it must also be divisible by 2.
- (d) All integers are rational numbers. This is true, since any integer number n can be written as $n/1$.
- (e) Any integer that is divisible by 2 or 3 is also divisible by 6. This is false—2 provides the easiest counterexample. Note that this statement is false even though its converse (part c) is true.
- (f) If a natural number is larger than 7, it can be written as the sum of two other natural numbers. This is trivially true, since we can take $a = x$ and $b = 0$.

(Aside: this is a reference to the very weak Goldbach Conjecture (<https://xkcd.com/1310/>).)

2 Truth Tables

Determine whether the following equivalences hold, by writing out truth tables. Clearly state whether or not each pair is equivalent.

(a) $P \wedge (Q \vee P) \equiv P \wedge Q$

(b) $(P \vee Q) \wedge R \equiv (P \wedge R) \vee (Q \wedge R)$

(c) $(P \wedge Q) \vee R \equiv (P \vee R) \wedge (Q \vee R)$

Solution:

(a) Not equivalent.

P	Q	$P \wedge (Q \vee P)$	$P \wedge Q$
T	T	T	T
T	F	T	F
F	T	F	F
F	F	F	F

(b) Equivalent.

P	Q	R	$(P \vee Q) \wedge R$	$(P \wedge R) \vee (Q \wedge R)$
T	T	T	T	T
T	T	F	F	F
T	F	T	T	T
T	F	F	F	F
F	T	T	T	T
F	T	F	F	F
F	F	T	F	F
F	F	F	F	F

(c) Equivalent.

P	Q	R	$(P \wedge Q) \vee R$	$(P \vee R) \wedge (Q \vee R)$
T	T	T	T	T
T	T	F	T	T
T	F	T	T	T
T	F	F	F	F
F	T	T	T	T
F	T	F	F	F
F	F	T	T	T
F	F	F	F	F

3 Necessary and Sufficient Conditions

(a) Given implication $A \implies B$, A is a _____ condition for B .

- (b) Given implication $\neg A \implies \neg B$, A is a _____ condition for B .
- (c) Given implication $\neg B \implies \neg A$, A is a _____ condition for B .
- (d) Given implication $B \implies A$, A is a _____ condition for B .

Solution:

- (a) Sufficient
- (b) Necessary
- (c) Sufficient
- (d) Necessary

4 Logical Equivalence?

Decide whether each of the following logical equivalences is correct and justify your answer.

- (a) $\forall x (P(x) \wedge Q(x)) \equiv \forall x P(x) \wedge \forall x Q(x)$
- (b) $\forall x (P(x) \vee Q(x)) \equiv \forall x P(x) \vee \forall x Q(x)$
- (c) $\exists x (P(x) \vee Q(x)) \equiv \exists x P(x) \vee \exists x Q(x)$
- (d) $\exists x (P(x) \wedge Q(x)) \equiv \exists x P(x) \wedge \exists x Q(x)$

Solution:

- (a) **Correct.**

Assume that the left hand side is true. Then we know for an arbitrary x $P(x) \wedge Q(x)$ is true. This means that both $\forall x P(x)$ and $\forall x Q(x)$. Therefore the right hand side is true. Now for the other direction assume that the right hand side is true. Since for any x $P(x)$ and for any y $Q(y)$ holds, then for an arbitrary x both $P(x)$ and $Q(x)$ must be true. Thus the left hand side is true.

- (b) **Incorrect.**

Note, there are many possible counterexamples - here we present only one. Suppose that the universe (i.e. the values that x can take on) is $\{1, 2\}$ and that P and Q are truth functions defined on this universe. If we set $P(1)$ to be true, $Q(1)$ to be false, $P(2)$ to be false and $Q(2)$ to be true, the left-hand side will be true, but the right-hand side will be false. Hence, we can find a universe and truth functions P and Q for which these two expressions have different values, so they must be different.

(c) **Correct**

Assuming that the left hand side is true, we know there exists some x such that one of $P(x)$ and $Q(x)$ is true. Thus $\exists x P(x)$ or $\exists x Q(x)$ and the right hand side is true. To prove the other direction, assume the left hand side is false. Then there does not exist an x for which $P(x) \vee Q(x)$ is true, which means there is no x for which $P(x)$ or $Q(x)$ is true. Therefore the right hand side is false.

(d) **Incorrect.**

Note, there are many possible counterexamples - here we present only one. Suppose that the universe (i.e. the values that x can take on) is the natural numbers \mathbb{N} , and that P and Q are truth functions defined on this universe. If we set $P(1)$ to be true and $P(x)$ to be false for all other x , and $Q(2)$ to be true and $Q(x)$ to be false for all other x , then the right hand side would be true. However, there would be no value of x at which both $P(x)$ and $Q(x)$ would be simultaneously true, so the left hand side would be false. Hence, we can find a universe and truth functions P and Q for which these two expressions have different values, so they must be different.