

3.11 Monotone Convergence Theorem

Suppose (X, \mathcal{S}, μ) is a measure space and $0 \leq f_1 \leq f_2 \leq \dots$ is an increasing sequence of \mathcal{S} -measurable functions. Define $f: X \rightarrow [0, \infty]$ by

$$f(x) = \lim_{k \rightarrow \infty} f_k(x).$$

Then

$$\lim_{k \rightarrow \infty} \int f_k d\mu = \int f d\mu.$$

Proof The function f is \mathcal{S} -measurable by 2.53.

Because $f_k(x) \leq f(x)$ for every $x \in X$, we have $\int f_k d\mu \leq \int f d\mu$ for each $k \in \mathbf{Z}^+$ (by 3.8). Thus $\lim_{k \rightarrow \infty} \int f_k d\mu \leq \int f d\mu$.

To prove the inequality in the other direction, suppose A_1, \dots, A_m are disjoint sets in \mathcal{S} and $c_1, \dots, c_m \in [0, \infty)$ are such that

$$3.12 \quad f(x) \geq \sum_{j=1}^m c_j \chi_{A_j}(x) \quad \text{for every } x \in X.$$

Let $t \in (0, 1)$. For $k \in \mathbf{Z}^+$, let

$$E_k = \left\{ x \in X : f_k(x) \geq t \sum_{j=1}^m c_j \chi_{A_j}(x) \right\}.$$

Then $E_1 \subseteq E_2 \subseteq \dots$ is an increasing sequence of sets in \mathcal{S} whose union equals X . Thus $\lim_{k \rightarrow \infty} \mu(A_j \cap E_k) = \mu(A_j)$ for each $j \in \{1, \dots, m\}$ (by 2.59).

If $k \in \mathbf{Z}^+$, then

$$f_k(x) \geq \sum_{j=1}^m t c_j \chi_{A_j \cap E_k}(x)$$

for every $x \in X$. Thus (by 3.9)

$$\int f_k d\mu \geq t \sum_{j=1}^m c_j \mu(A_j \cap E_k).$$

Taking the limit as $k \rightarrow \infty$ of both sides of the inequality above gives

$$\lim_{k \rightarrow \infty} \int f_k d\mu \geq t \sum_{j=1}^m c_j \mu(A_j).$$

Now taking the limit as t increases to 1 shows that

$$\lim_{k \rightarrow \infty} \int f_k d\mu \geq \sum_{j=1}^m c_j \mu(A_j).$$

Taking the supremum of the inequality above over all \mathcal{S} -partitions A_1, \dots, A_m of X and all $c_1, \dots, c_m \in [0, \infty)$ satisfying 3.12 shows (using 3.9) that we have $\lim_{k \rightarrow \infty} \int f_k d\mu \geq \int f d\mu$, completing the proof. \blacksquare

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