

### 3.11 Monotone Convergence Theorem

Suppose  $(X, \mathcal{S}, \mu)$  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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